

Fall 2018 IceBridge DC-8 Flight Plans
3 October 2018 Draft

compiled by

John Sonntag

Introduction to Flight Plans

This document is a translation of the NASA Operation IceBridge (OIB) scientific objectives articulated in the Level 1 OIB Science Requirements, at the June IceBridge Antarctic planning meeting held at the University of California at Irvine, through official science team telecons and through e-mail communication and iterations into a series of operationally realistic flight plans, intended to be flown by NASA's DC-8 aircraft, beginning in early October and ending in late November 2018. The material is shown on the following pages in the distilled form of a map and brief text description of each science flight. Google Earth (KML) versions of these flight plans are also available.

For each planned mission, we give a map and brief text description for the mission. The missions are planned to be flown from Punta Arenas, Chile. A careful reader may notice that some of the mission maps in the main part of the document highlight flightlines in green, yellow, and red colors, while other only show the black lines. The colors are a refinement added to the flight plans at a late stage of design which help the field team navigate the aircraft properly to achieve specific science goals. The colors represent the degree of “straightness” of each flight segment, where straight segments are steered using an automated technique and curved sections using a specialized manual method. Not all of the flight plans shown here have necessarily reached that mature stage of design.

In fact, as a general rule the flight plans depicted here are all at varying stages of completeness. For each mission we note “Remaining Design Issues” to be resolved, if any exist. In most cases these are minor. Spacecraft underflights are a major exception, since these have to be re-planned for each potential flight day (for sea ice) or within a window of several potential flight days (for land ice). Sea ice camp/site overflights are also an exception, since these move with the motion of the ice, unless they are situated on shore-fast ice.

Note that this document shows 33 planned land ice and 5 planned sea ice missions, which is more than we expect to fly this year. The extra flight plans give us operational flexibility to fly as much as possible, and scientifically productive, while we are in the field. The entire suite of 38 flight plans is depicted in the introductory material following this text, with each flight prioritized as described next. Each flight has a priority assigned to it by the OIB science team, either baseline, high, medium or low, and these are listed below with each mission.

For previous Operation IceBridge campaigns, this document included composite maps, showing how multiple flight plans related to each other in specific regions. With the exception of the composite map of the entire study area given near the top of this document, we no longer include such maps. Instead, the KMZ files (link shown above) provide similar visual information in a more versatile form.

Avoidance of overflights of known Antarctic wildlife colonies and designated protected areas is a high priority for NASA. We include an Appendix at the end of this document which details our approach for doing so.

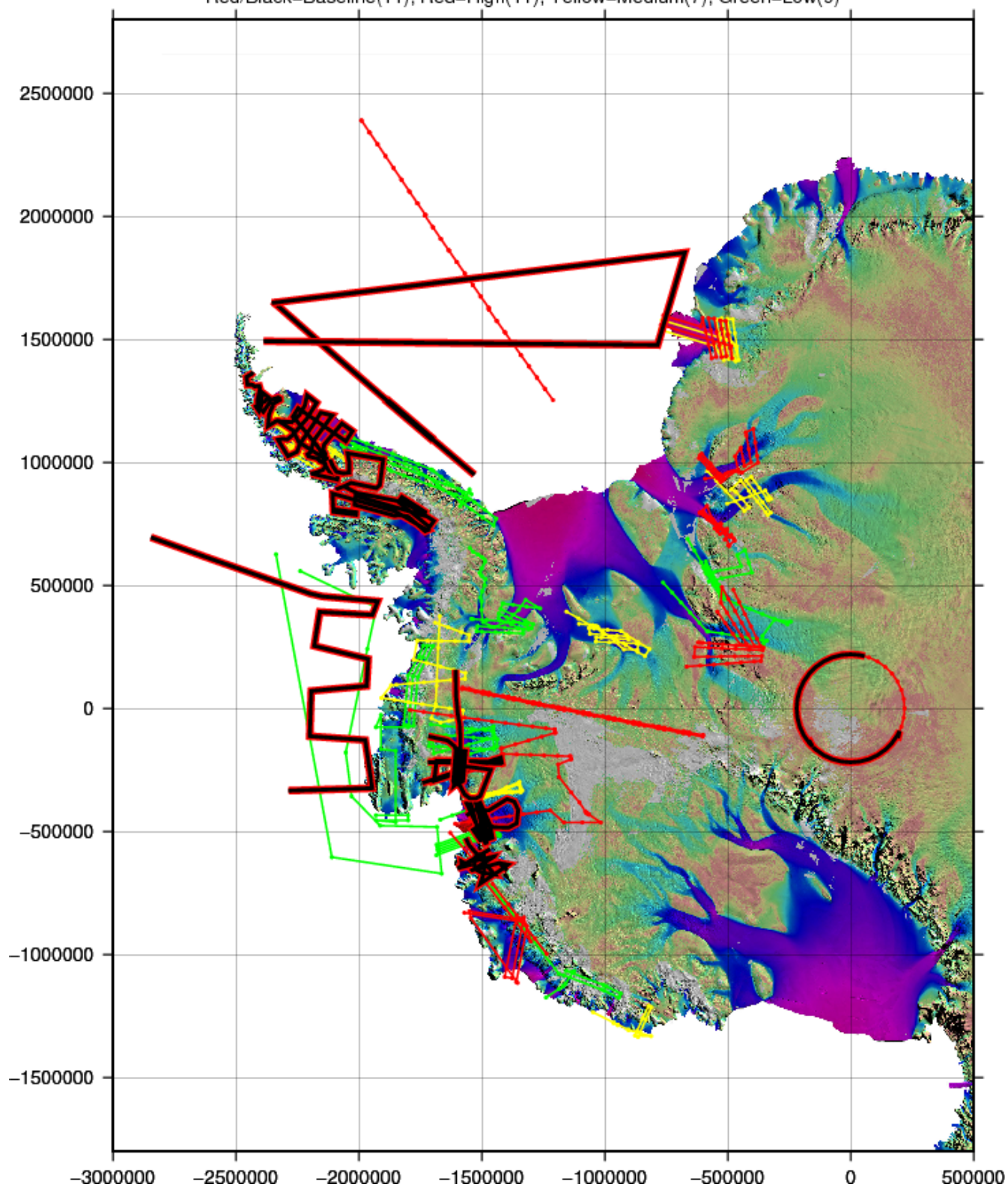
With the launch of NASA's ICESat-2 scheduled for 15 September 2018, OIB enters a new phase for this year's fall campaign. We augment our “bridge” function and all the other traditional IceBridge functions with new efforts intended to assist with the commissioning of the new spacecraft, including calibration and validation. To that end we have revamped our suite of flight plans to a large degree. We have for the most part retained the traditional “baseline” land and sea ice missions of IceBridge, although we have replaced some of their individual lines with ICESat-2 ground tracks where that was

appropriate. We have modified the Hamilton Line / Pole Hole flights to include 90 degree crossovers to assist the ATM team in applying the best possible pitch and roll bias calibrations to that key data. But we have replaced most of the older, lower-priority dh/dt oriented flights with new versions in the same areas, built around ICESat-2 ground tracks. We have retained the ice shelf oriented missions that were not flown in prior years, in the expectation that we will operate a gravimeter this season. But we have also designed several new missions designed primarily to assist with the ICESat-2 calibration and validation effort.

These ICESat-2 (often abbreviated “IS-2”) cal/val missions require a number of new considerations for IceBridge operations. For the sea ice portion of the effort, at least one mission is desired to be flown in darkness or at least low light, to help understand the effects of ambient lighting on the ICESat-2 range retrieval algorithm. Very low time separation between the IS-2 sea ice cal/val missions is also a high priority. For land ice, some of the new missions also have sensitivity to time latency, and these must be redesigned on a regular basis until they are flown. The sensitivity of each flight to IceSat-2 latency is identified in the text, and the ones which must be redesigned on a regular basis are also highlighted with red text. Also, for some of the land ice missions we desire to use the new ATM T-7 dual color narrow-swath sensor to investigate differential penetration into the surface of the green and IR signals. These missions in particular require very precise cross-track targeting in order to place the narrow ATM-T7 scan directly over one of the “strong” beams in the ICESat-2 footprint. Since the spacecraft will be in its commissioning phase during most or all of the deployment, many aspects of its operations will be in flux. Currently it is expected that the ability to point the spacecraft accurately at its desired surface targets will reach an acceptable level around 1 November, so for many of the low-latency ICESat-2 land ice cal/val missions we prefer to wait until then to fly them. We do not anticipate a major impact to our pace of flight operations to result from this constraint, because for the month of October we can still fly some sea ice missions, the traditional baseline land ice missions, the Hamilton Line missions (which are not sensitive to spacecraft pointing), and the ice shelf oriented missions.

Prioritized 2018 OIB DC-8 Antarctic Flights

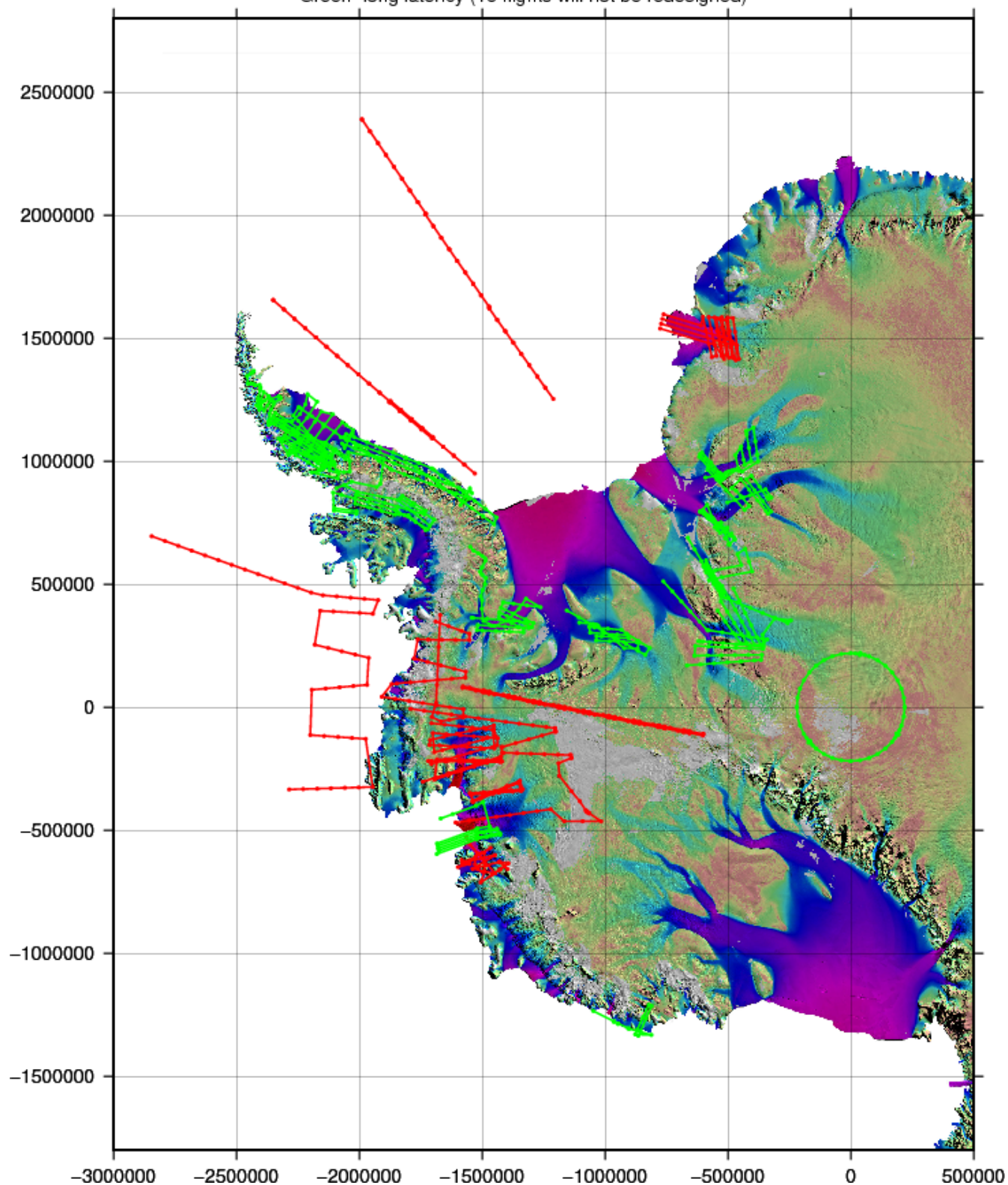
Red/Black=Baseline(11); Red=High(11); Yellow=Medium(7); Green=Low(9)



OIB IS-2 Calibration/Validation Flights

Red=short latency (12 flights to be redesigned according to timing)

Green=long latency (18 flights will not be redesigned)



Sea Ice – Bellingshausen 1

This mission represents a continuation of the IceBridge time series, repeating much of the 21 October 2009 and 30 October 2010 Sea Ice 01 flights and the 23 October 2011 and 13 October 2012 Bellingshausen 1 flights. The northern portion of this flight (i.e. between WP110n and 111n) may be adjusted according to sea ice coverage reports obtained just prior to (or during) the deployment, specifically the location of the ice edge. Also note that that segment of the flight may have to be flown at high altitude, depending on fuel constraints. This mission should be flown as early as possible, preferably before mid-Oct, because of the relatively early onset of melt of in this region.

Flight Priority: low

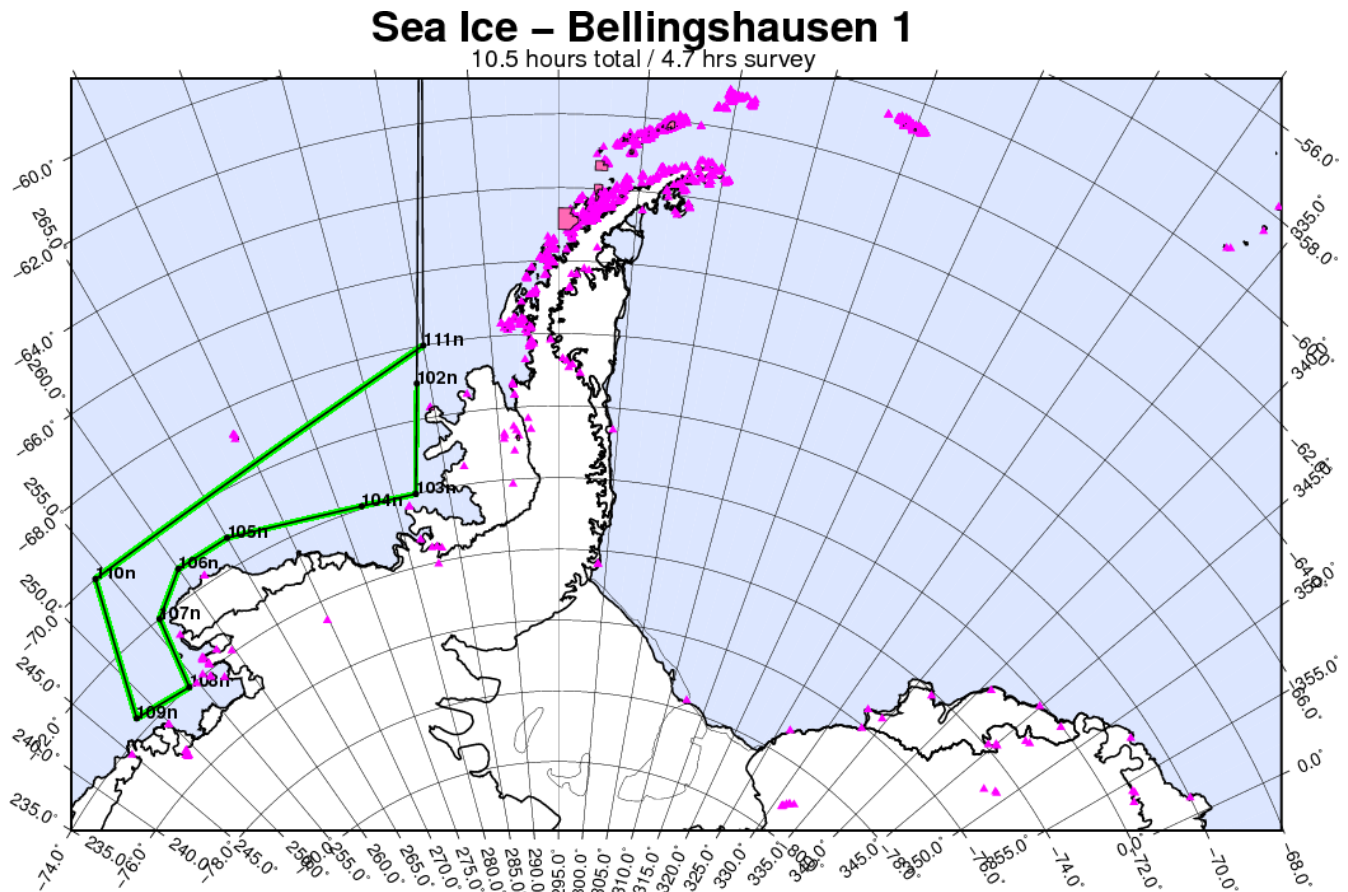
ICESat-2 latency: n/a

Science Requirements Addressed: SI1,SI2,SI3c,SI6

Spacecraft Tracks: none

Last Flown: 2014

Remaining Design Issues: none



Sea Ice – Bellingshausen 2

This mission is similar to the 2012 flight of the same name, but with the Envisat ground tracks replaced by ICESat-2 ground tracks. We also extend one of the IS-2 lines north to the ice edge and approximately 50 km beyond it, in order to capture the transition from open water, to marginal ice zone, to pack. This mission should be flown as early as possible, preferably before mid-October, because of the relatively early onset of melt of in this region.

Flight Priority: baseline

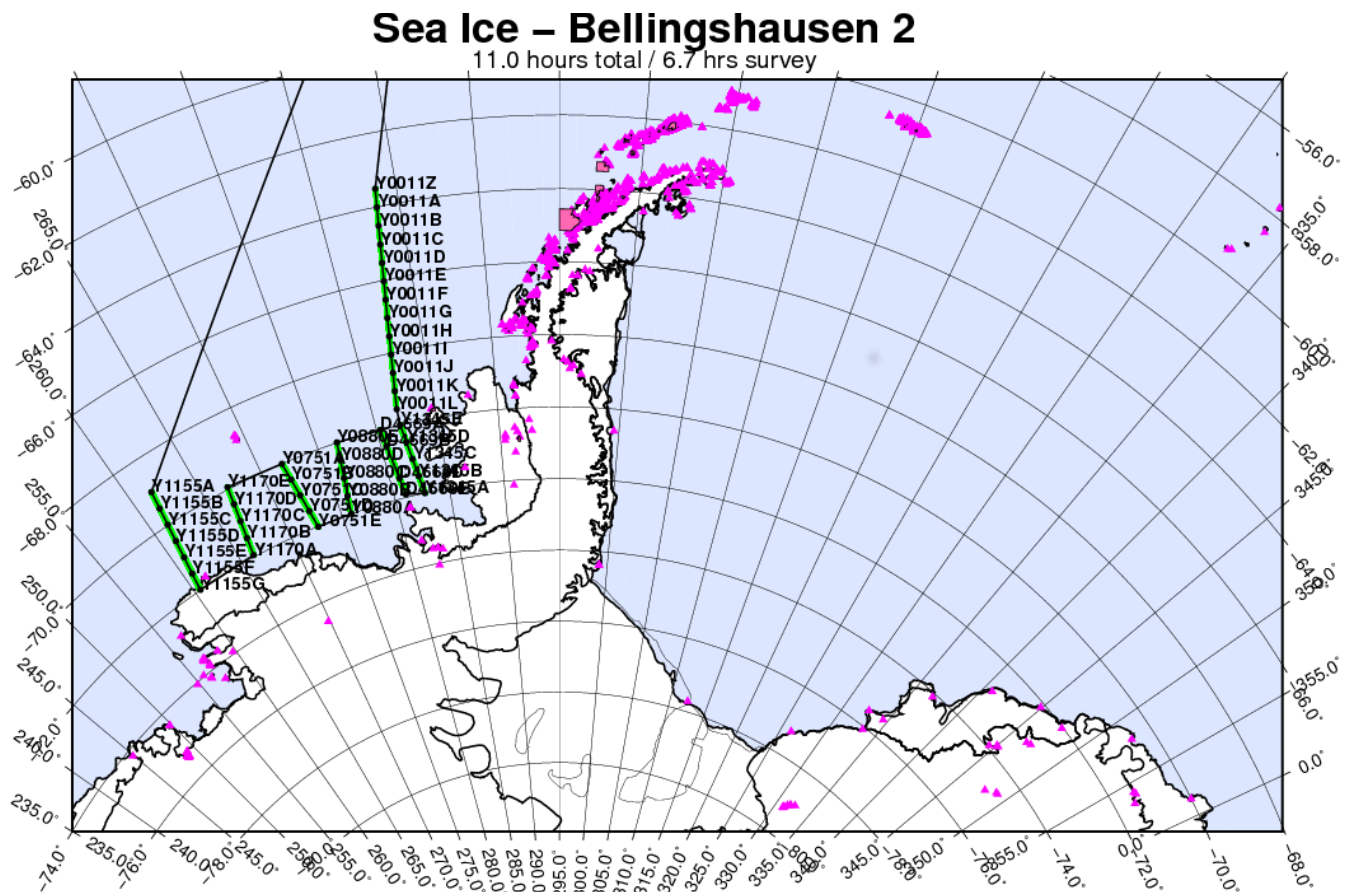
ICESat-2 latency: short if possible, for 1-2 lines

Science Requirements Addressed: SI1,SI2,SI3c,SI4,SI6

Spacecraft Tracks: Y0011,Y1345,D4669,Y0880,Y0751,Y1170,Y1155 (all ICESat-2)

Last Flown: 2016

Remaining Design Issues: replace any lines with time-coincident IS-2, CryoSat-2, or Sentinel-3a groundtracks



Sea Ice – West Weddell

This mission represents a continuation of a portion of the IceBridge “Endurance” time series, specifically the portion of that flight in the western Weddell Sea, near the Antarctic Peninsula. For 2018 this flight line will be an ICESat-2 ground track, selected so that the spacecraft will fly the line when OIB is on it, or as nearly so as can be arranged. We fly an out-and-back pattern along the center beam pair, but we augment this with a partially repeated S-pattern, flying all three beam pairs once, and the two TEP beam pairs twice, around 69 S latitude. This pattern can be done on either the northbound or southbound leg, but it is preferable to conduct it as close in time as possible to the ICESat-2 pass. Finally, we correct all waypoints in real-time with a periodic drift correction (see Appendix C), the intention of which is to improve the likelihood that ICESat-2 and OIB measure the same swath of drifting sea ice.

Flight Priority: BASELINE

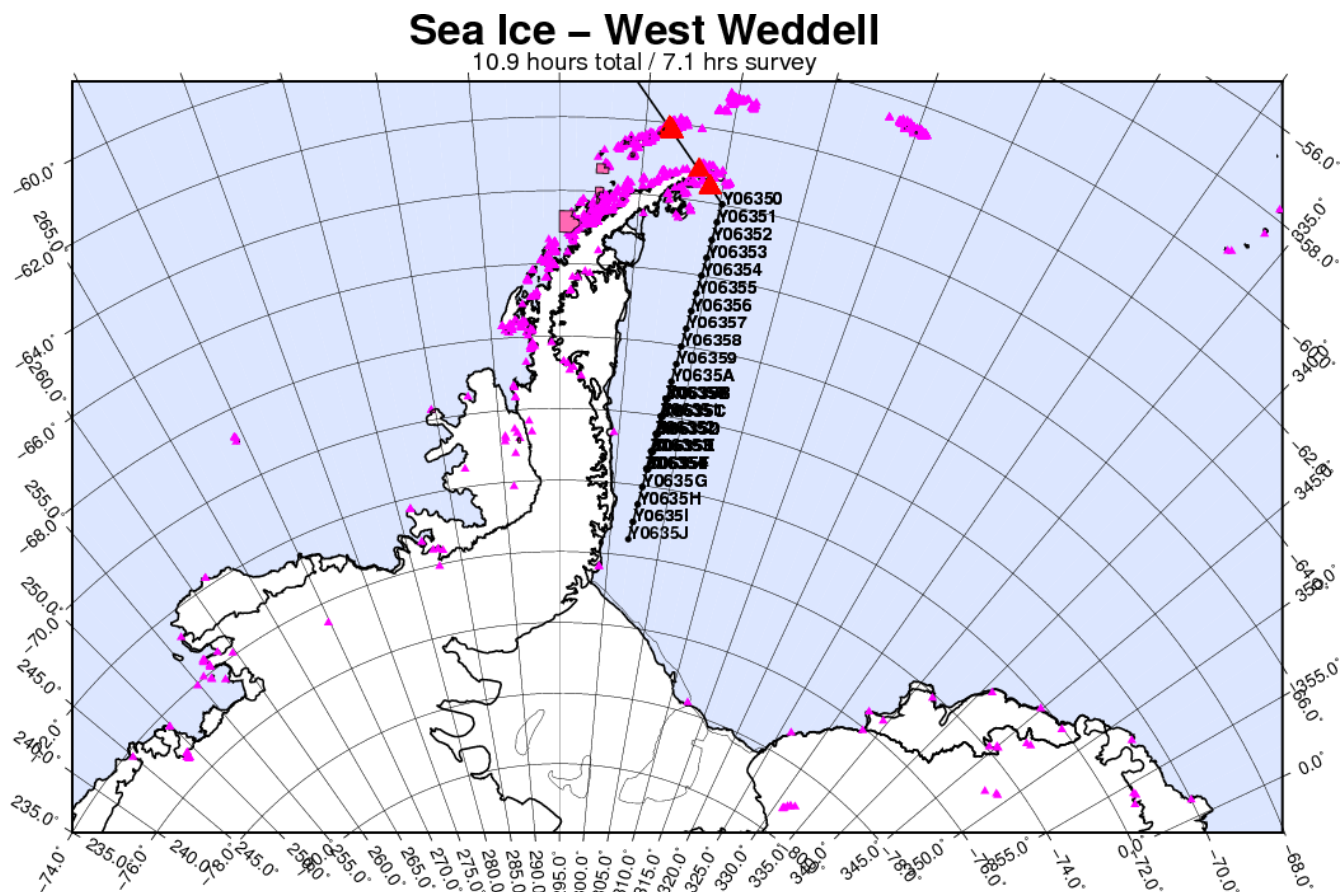
ICESat-2 latency: short

Science Requirements Addressed: SI1,SI2,SI3b,SI4,SI6

Spacecraft Tracks: TBD

Last Flown: new flight

Remaining Design Issues: none



Sea Ice – Mid-Weddell

This mission represents a continuation of a portion of the IceBridge “Endurance” time series, specifically the portion of that flight in the central Weddell Sea. For 2018 this flight line will be an ICESat-2 ground track, selected so that the spacecraft will fly the line when OIB is on it, or as nearly so as can be arranged. We fly an out-and-back pattern, switching between the left, center and right beam pairs. Finally, we correct all waypoints in real-time with a periodic drift correction (see Appendix C), the intention of which is to improve the likelihood that ICESat-2 and OIB measure the same swath of drifting sea ice.

Flight Priority: high

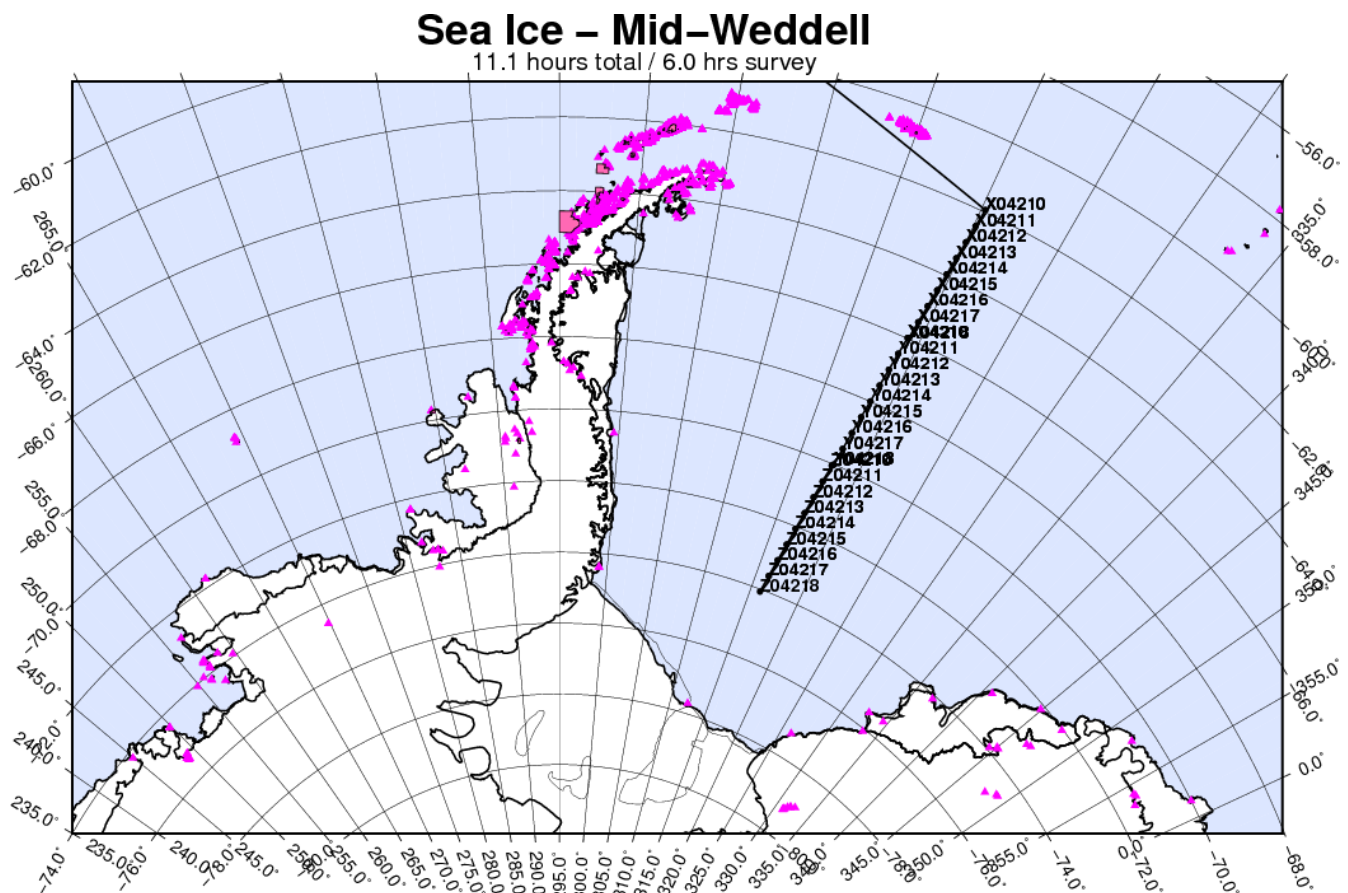
ICESat-2 latency: short

Science Requirements Addressed: SI1,SI2,SI3b,SI4,SI6

Spacecraft Tracks: 0421

Last Flown: new flight

Remaining Design Issues: none



Sea Ice – Seelye Loop

This mission represents a continuation of the IceBridge time series, repeating the 24 October 2009, 26 October 2010, 12 October 2011 and 25 October 2011 missions. It was not flown in 2012 due to persistent poor weather that year. It targets gradients in sea ice freeboard and thickness along the “gate” connecting the tip of the Antarctic Peninsula with Cape Norvegia. This mission may have to be shortened if dictated by fuel constraints.

Flight Priority: BASELINE

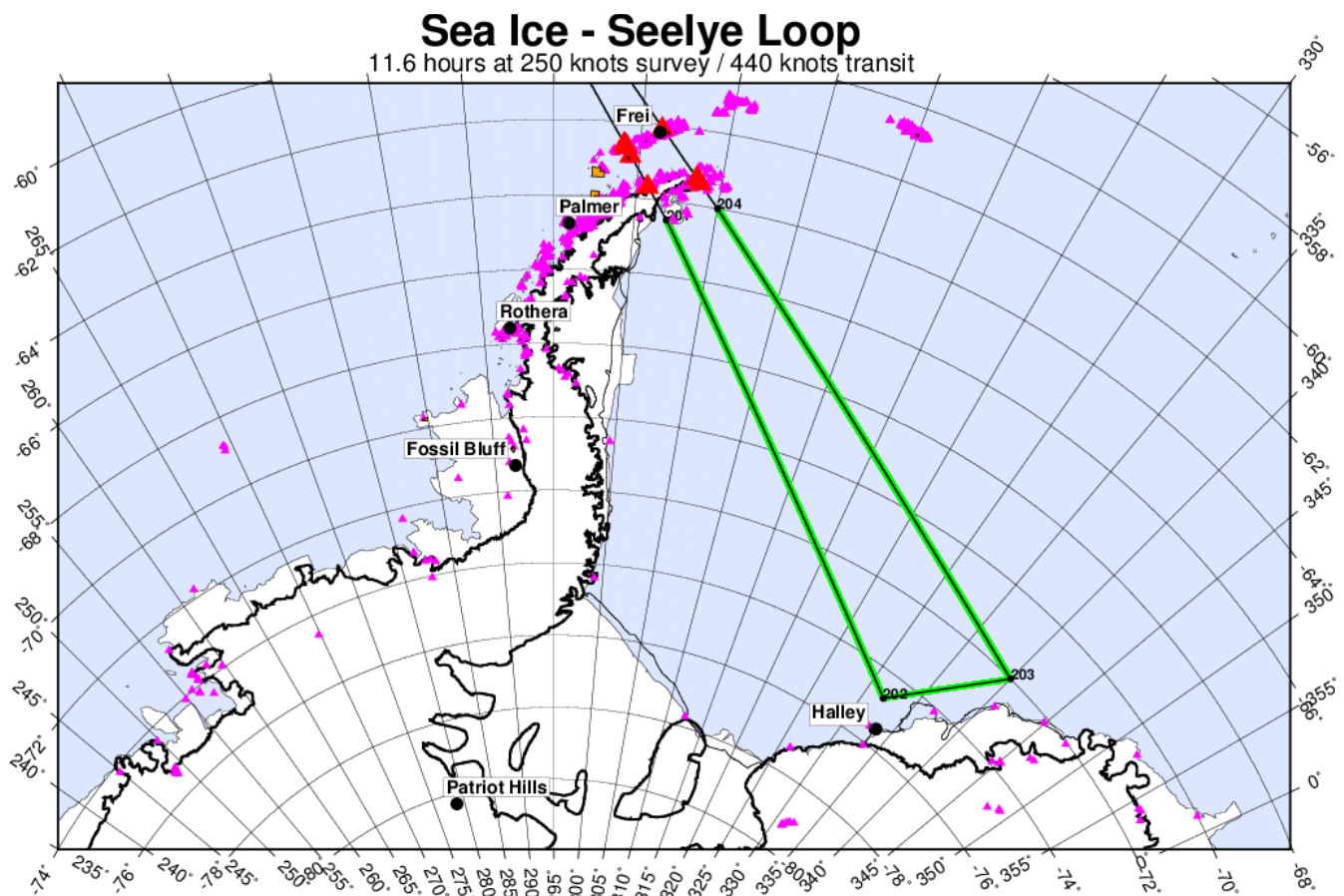
ICESat-2 latency: n/a

Science Requirements Addressed: SI1,SI2,SI3a,SI6,SI9

Spacecraft Tracks: none

Last Flown: 2016

Remaining Design Issues: none; do not modify for any spacecraft ground tracks



Land Ice – Nickerson IS-2

This is a new mission, designed to fill several voids in gravity and radar measurements of the Nickerson Ice Shelf identified by Romain Millain. It does this by extending a previous 10-km coast-parallel grid offshore by an additional line, and by flying a pair of ICESat-2 lines over an unmapped embayment of the ice shelf near the western end of the DC-8's range from Punta Arenas.

Flight Priority: medium

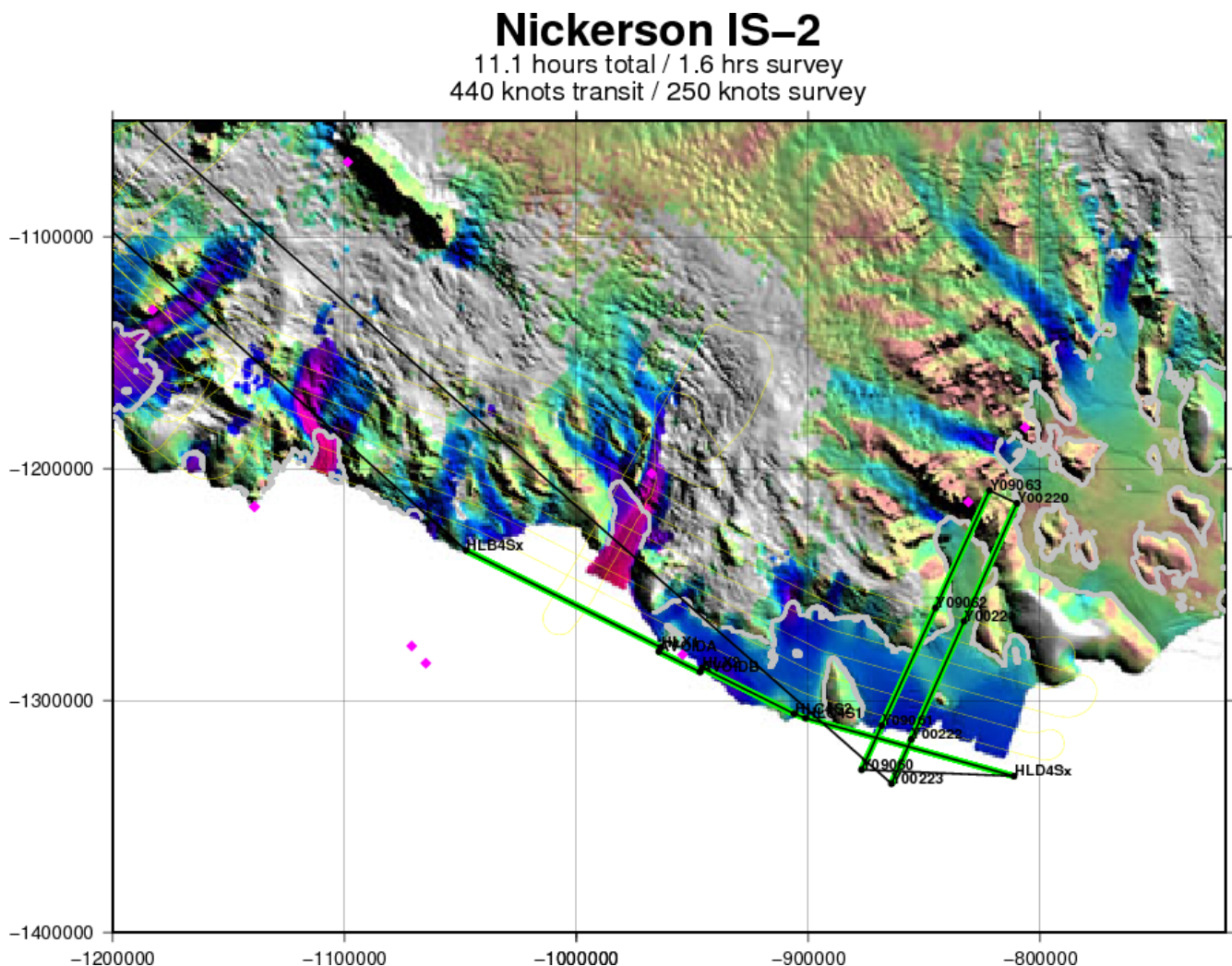
ICESat-2 latency: long

Science Requirements Addressed: IS1,IS3,IS4,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: Y0906,Y0022 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Hull-Land 05

This is a new mission, one of a suite of five designed to map the coastal region encompassing the Hull and Land glaciers and surrounding areas to the west of the Getz Ice Shelf. The twofold purpose is to map the bathymetry and basal topography using the gravimeter and MCoRDS radar, and at the same time to establish surface topography measurements for dh/dt. This particular flight is the most inboard of the five planned flights, and it increases the spacing of the lines from 10 km to 20 km, mainly for the purpose of extending the surveys to the base of the Flood Range. It also includes a centerline survey of the Berry Glacier, and the curvature of this line may be small enough to enable the line to be suitable as a gravity tie line as well. Finally we overfly an LVIS grid line in the Getz area during the inbound transit at high altitude, to obtain high-altitude data on an opportunistic basis.

Flight Priority: low

ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS3,IS4,IS7,IS11,IS12,IS13,IS15

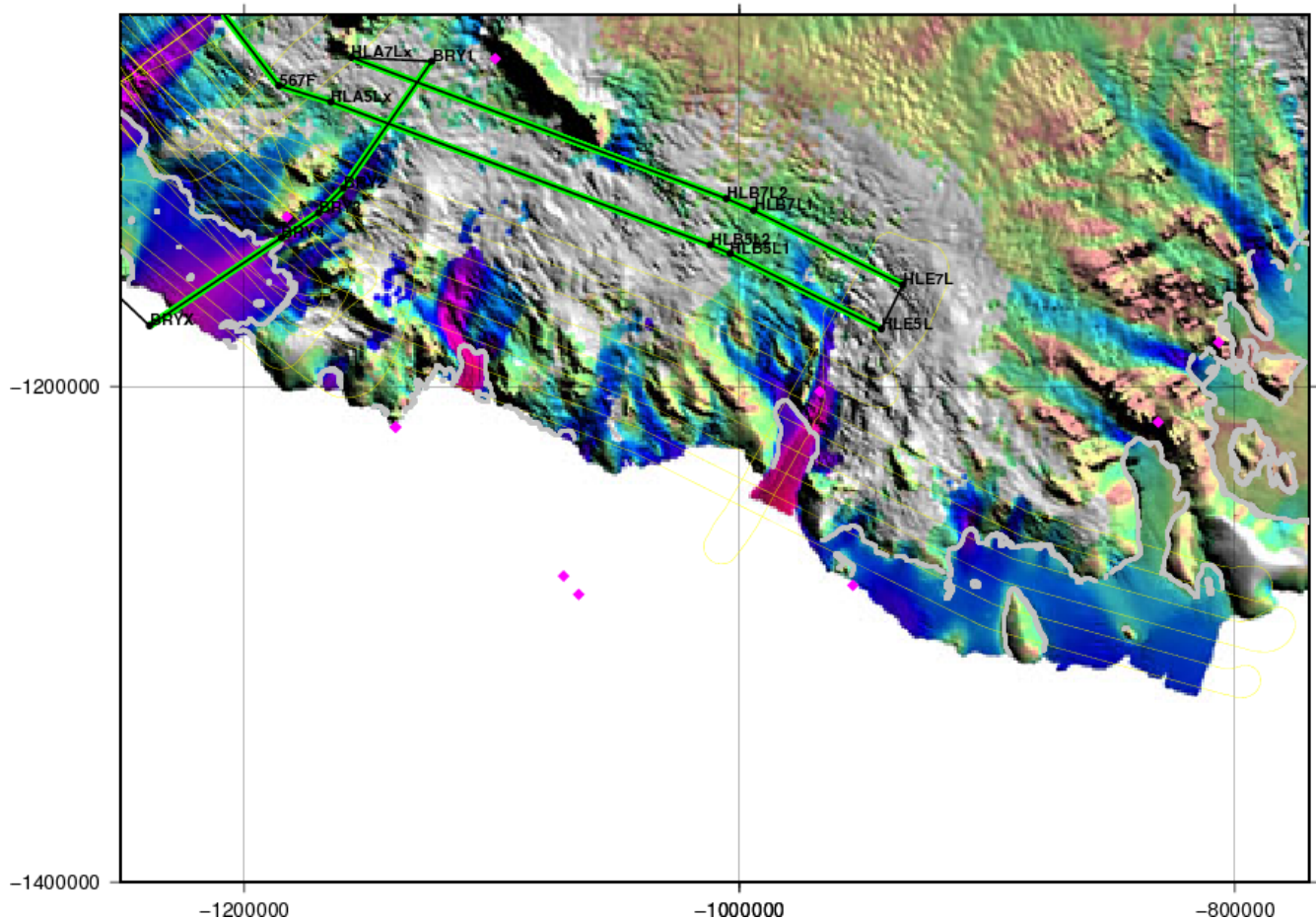
Spacecraft Tracks: none

Last Flown: new flight

Remaining Design Issues: none

Hull-Land 05

10.6 hours total / 2.4 hrs survey
440 knots transit / 250 knots survey



Land Ice – Getz 06

This is a new mission, one of a suite of four designed to supplement the 2009-2012 Getz Ice Shelf flights. The twofold purpose is to continue mapping the sub ice-shelf bathymetry using the gravimeter, and to continue mapping the ice surface and bedrock upstream of the grounding line. This particular flight primarily focuses on obtaining coverage of the main eastern and western “outlets” of the Getz Ice Shelf, complementing coverage obtained there in the Getz 08 flight. These lines also serve as gravity tie lines for other flightlines traversing this region. Finally, we obtain a tie line over a suspected overdeepened area beneath the Crosson Ice Shelf.

Flight Priority: high

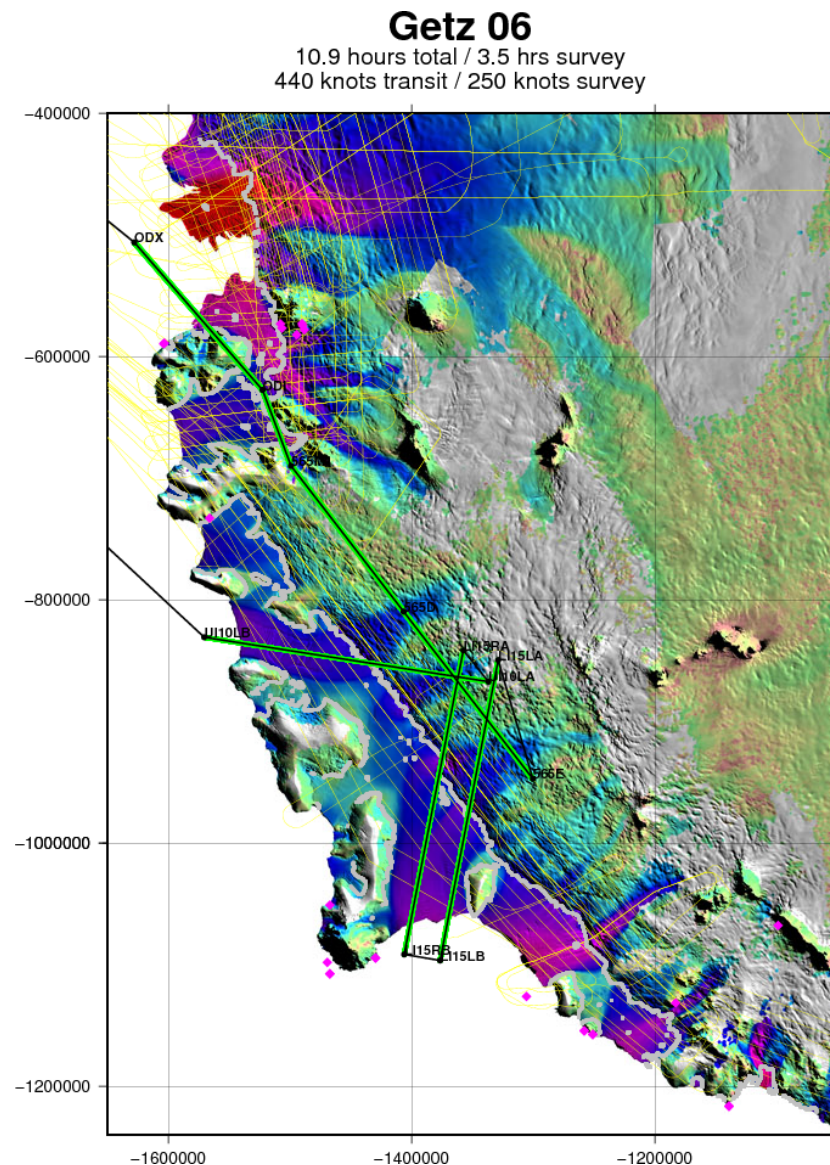
ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS3,IS4,IS7,IS13,IS15

Spacecraft Tracks: none

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Getz 08

This is a new mission, one of a suite of four designed to supplement the 2009-2011 Getz Ice Shelf flights. The twofold purpose is to continue mapping the sub ice-shelf bathymetry using the gravimeter, and to continue mapping the ice surface and bedrock upstream of the grounding line. This particular flight focuses on the upper-most portion of the region, and it also includes a pair of tie lines, running roughly parallel to the flow direction of the eastern and western “outlets” of the Getz Ice Shelf. These lines are supplemented by additional parallel lines in the Getz 06 flight. We also add a tie line across the two large islands outboard of the ice shelf.

Flight Priority: high

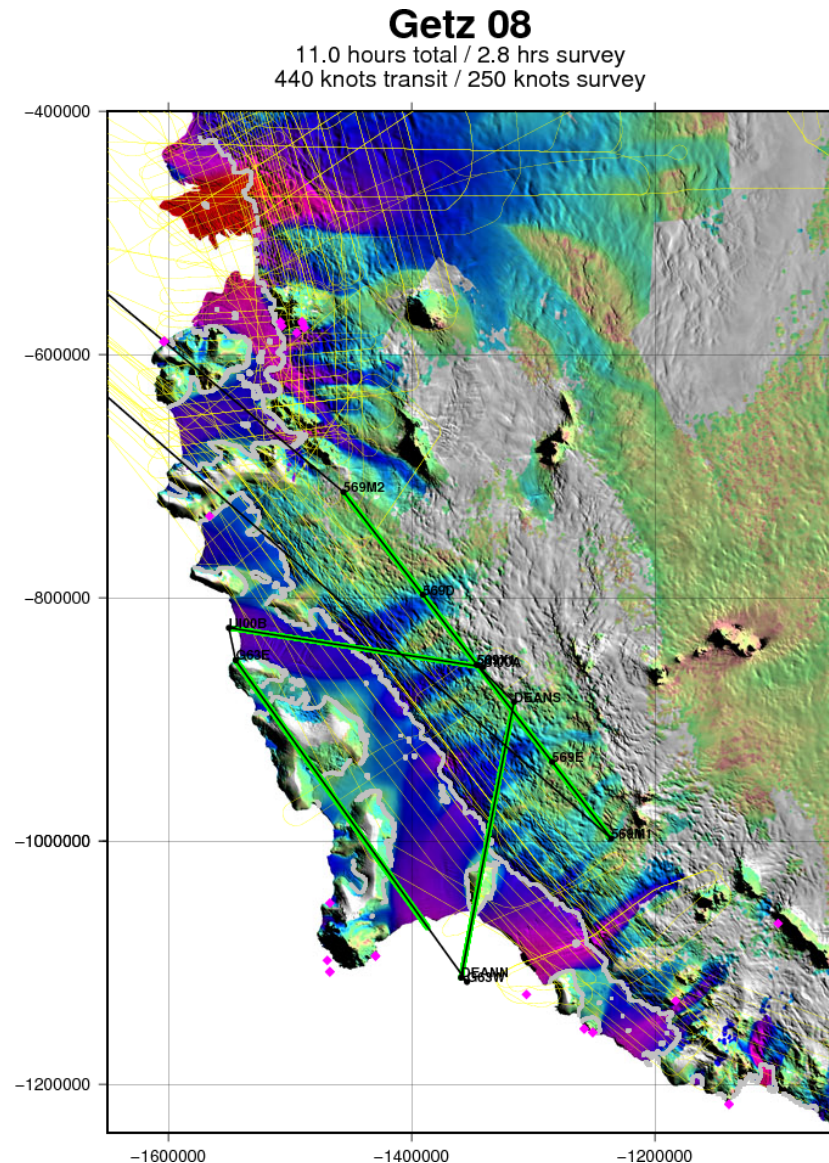
ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: none

Last Flown: new flight

Remaining Design Issues: fly through -74.61934 -127.34280 on western outlet (late change)



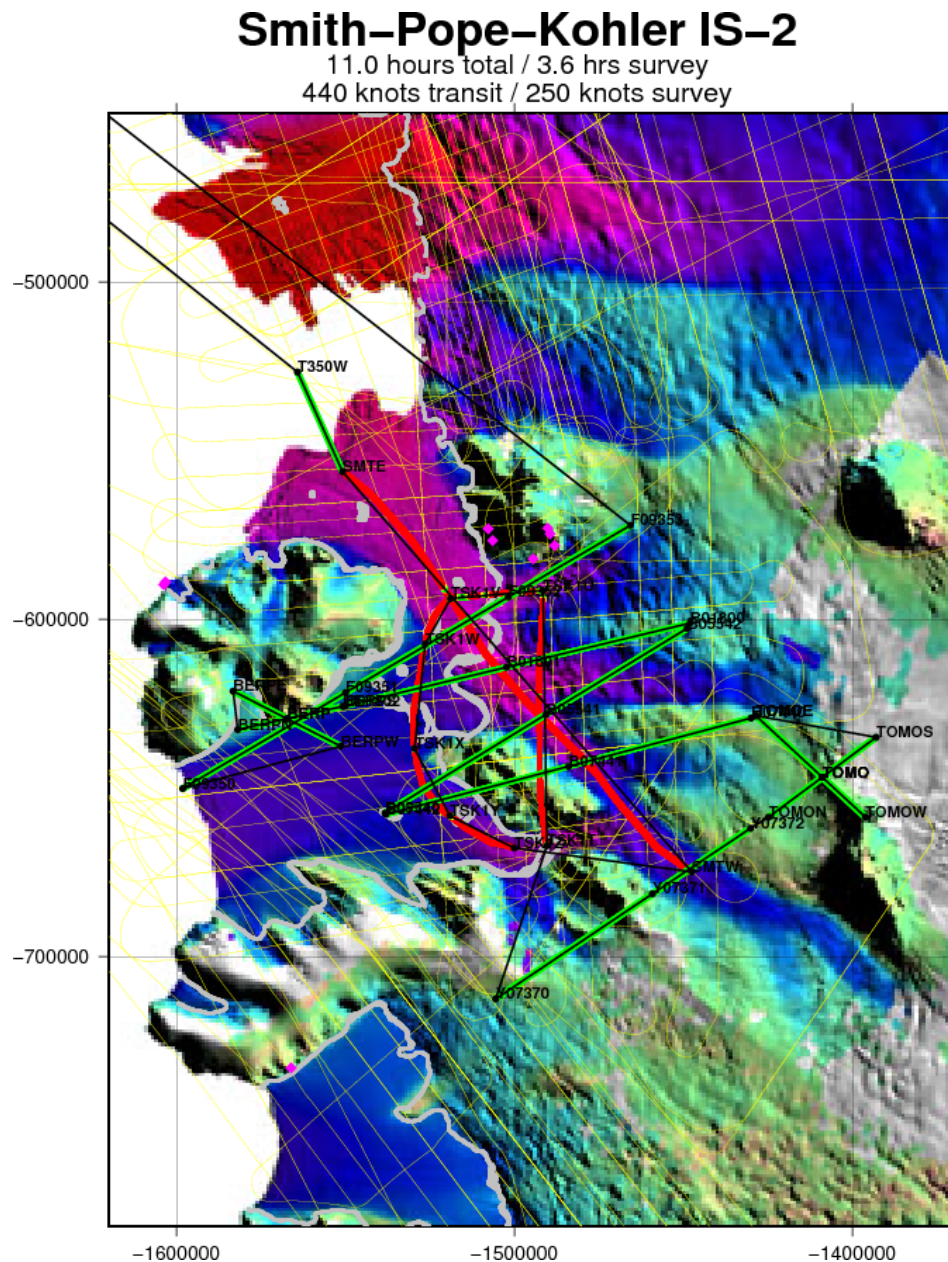
This mission is designed to collect surface dh/dt measurements over the Dotson and Crosson Ice Shelves and over the lower Smith, Kohler and Pope Glaciers. The flightlines are designed along ICESat-2 ground tracks and along historical ATM lines dating back to 2002. We also add crossing overflights of two permanent GPS stations at Bear Peninsula and Toney Mountain, to assist with calibration and validation of ATM measurements.

ICESat-2 latency: short

Spacecraft Tracks: Y0737,B0744,B0554,B0180,F0935 (ICESat-2)

Last Flown: portions in 2016

Remaining Design Issues: none



Land Ice – Thwaites NERC/NSF

This mission is designed to supplement the upcoming (February 2019) NERC/NSF Thwaites effort with an OIB mission, targeting a number of ICESat-2 ground tracks between Thwaites and Mt. Murphy. These lines are supplemented with several offshore gravity lines which supplement the NERC/NSF surveys.

Flight Priority: low

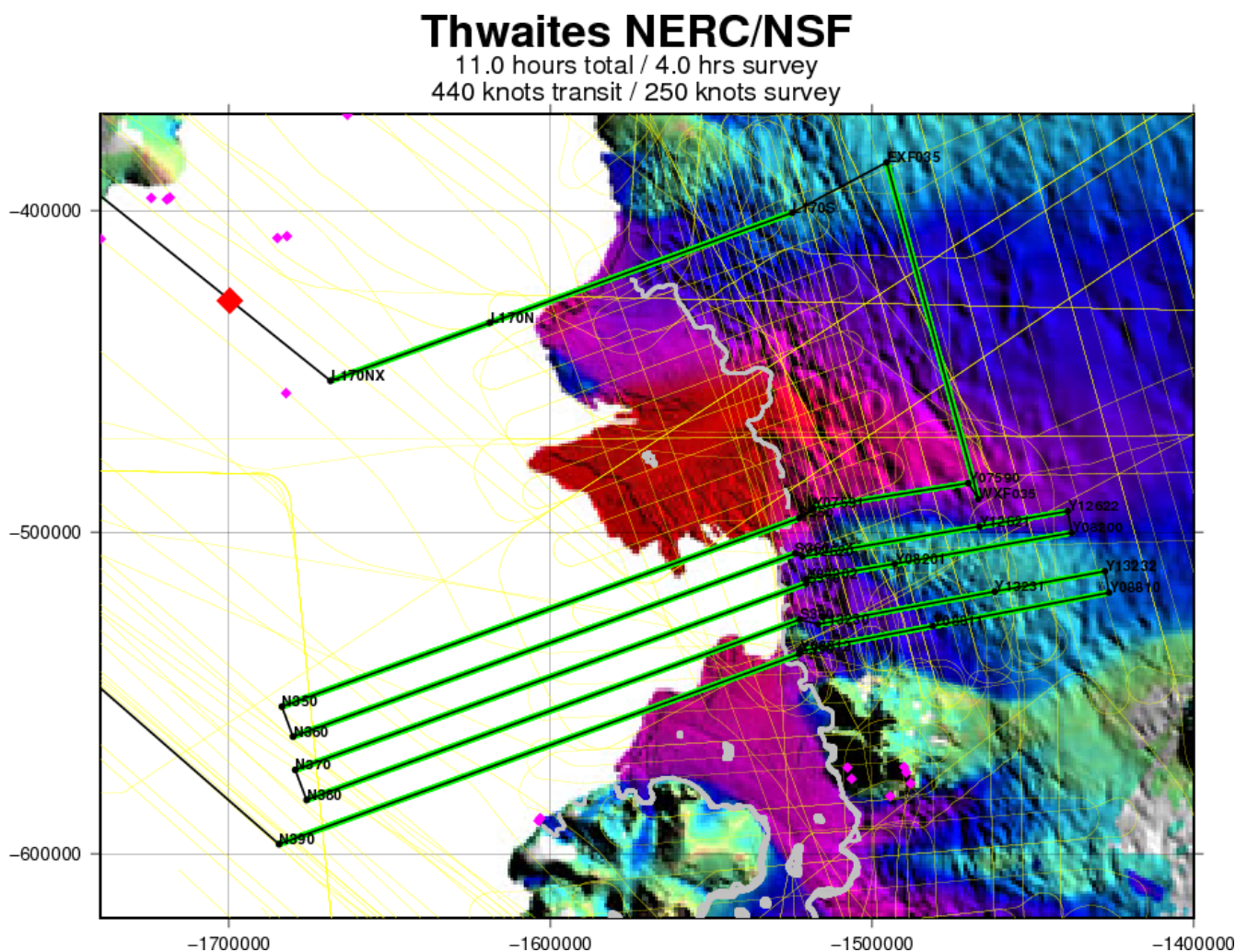
ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13

Spacecraft Tracks: Y0759,Y1262,Y0820,Y1323,Y0881

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Thwaites 2002

This mission is an amalgamation of previous OIB Thwaites flights, and is primarily intended to retain the portions of those flights which in turn repeated the 2002 NASA/Chilean lines. This yields a very long dh/dt time history of measurements along these lines.

Flight Priority: BASELINE (multi-year repeat flight)

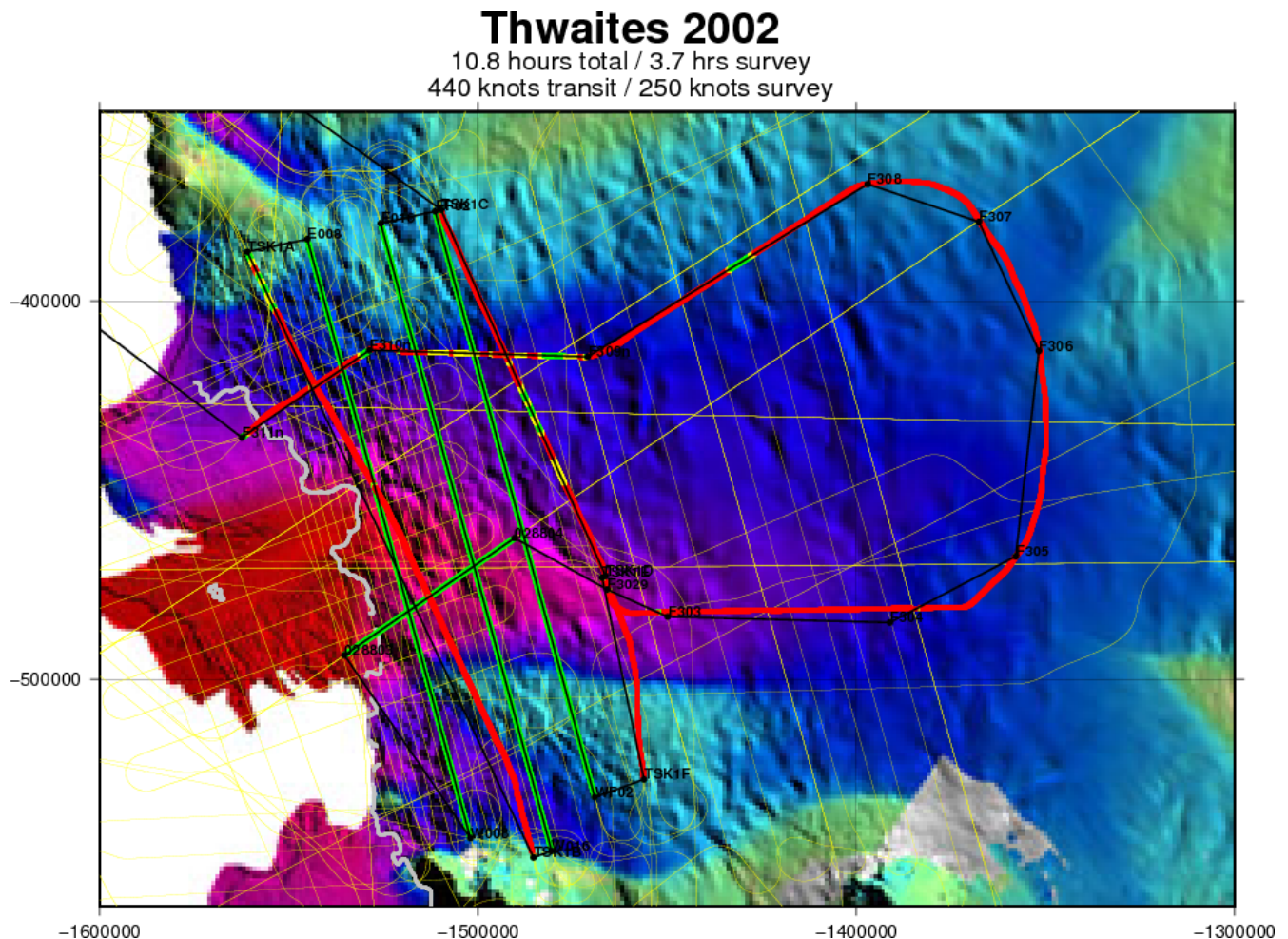
ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: 0288 (ICESat-1)

Last Flown: 2016

Remaining Design Issues: none



Land Ice – Thwaites-Getz 3 Beam IS-2

This new mission is designed to fly all three beam pairs of two crossing, low-latency, ICESat-2 ground tracks. These two low-latency tracks can be placed anywhere between the eastern shear margin of Thwaites Glacier, and roughly the eastern end of the Getz Ice Shelf, and above the grounding line.

Flight Priority: medium

ICESat-2 latency: short

Science Requirements Addressed: P1,P2,P3,P4,IS7,IS10,IS11,IS12,IS13

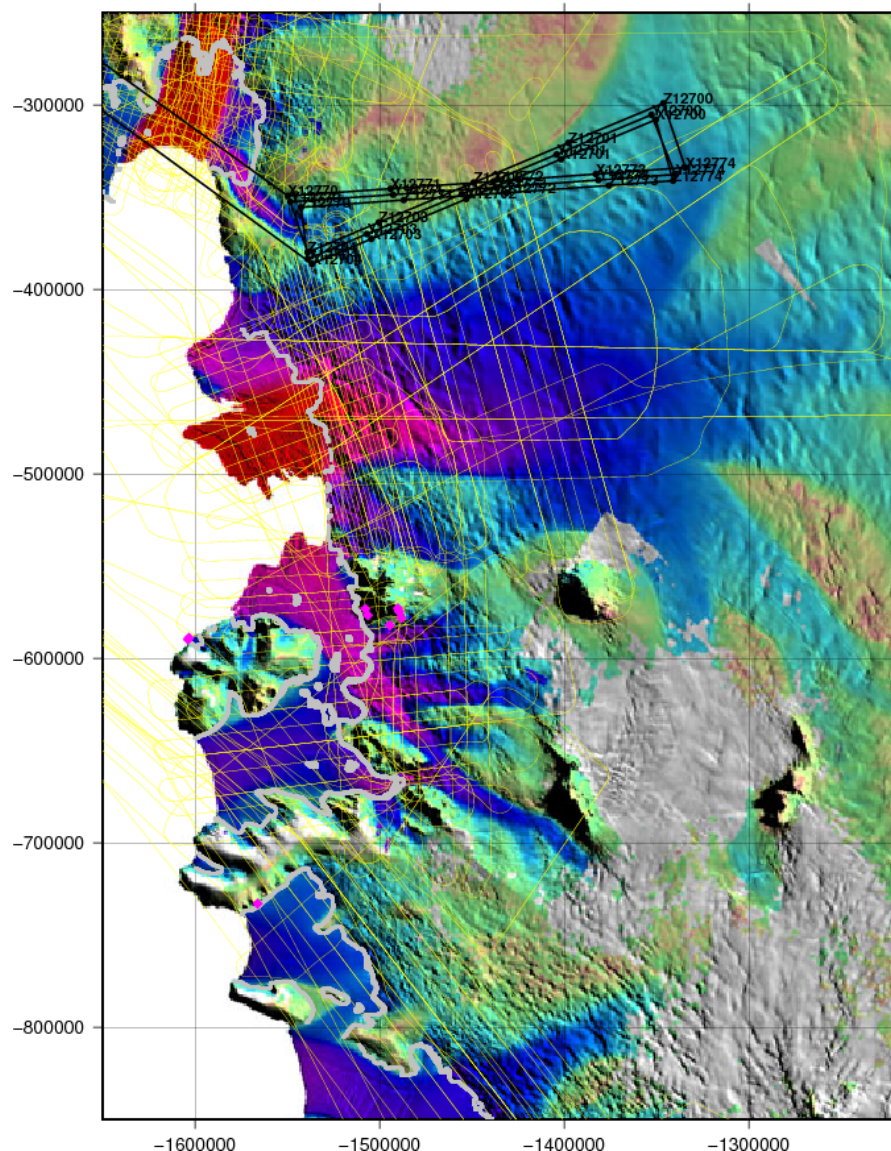
Spacecraft Tracks: X1277,Z1270,Y1277,Y1270,Z1277,X1270 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Thwaites–Getz 3 Beam IS–2

10.6 hours total / 3.6 hrs survey
440 knots transit / 250 knots survey



Land Ice – ICESat-2 WAIS Cores

This mission is designed to collect baseline measurements along planned ICESat-2 ground tracks. Most of the lines are located between the Pine Island and Thwaites channels, where the ice is expected to change relatively slowly, making this a suitable area for comparisons with future ICESat-2 measurements. This is also an area with relatively few dh/dt measurements collected to date, making it desirable to collect measurements of background change rates outside the fast-changing outlets. We also broaden the ice types measured with overflights of ICESat-2 ground tracks over lower Thwaites and upper Pine Island channels. We target left, center and right IS-2 beam pairs each with two ground tracks. The western portion of the flight is a partial repeat of the 2011 WAIS Cores mission, which crosses the WAIS ice divide and also overflies several ice core sites. The aircraft should overfly each core site in a straight and level attitude in order to maintain best radar performance for layer detection.

Flight Priority: high (multi-year repeat flight)

ICESat-2 latency: short

Science Requirements Addressed: P1,P2,P3,IS6,IS12

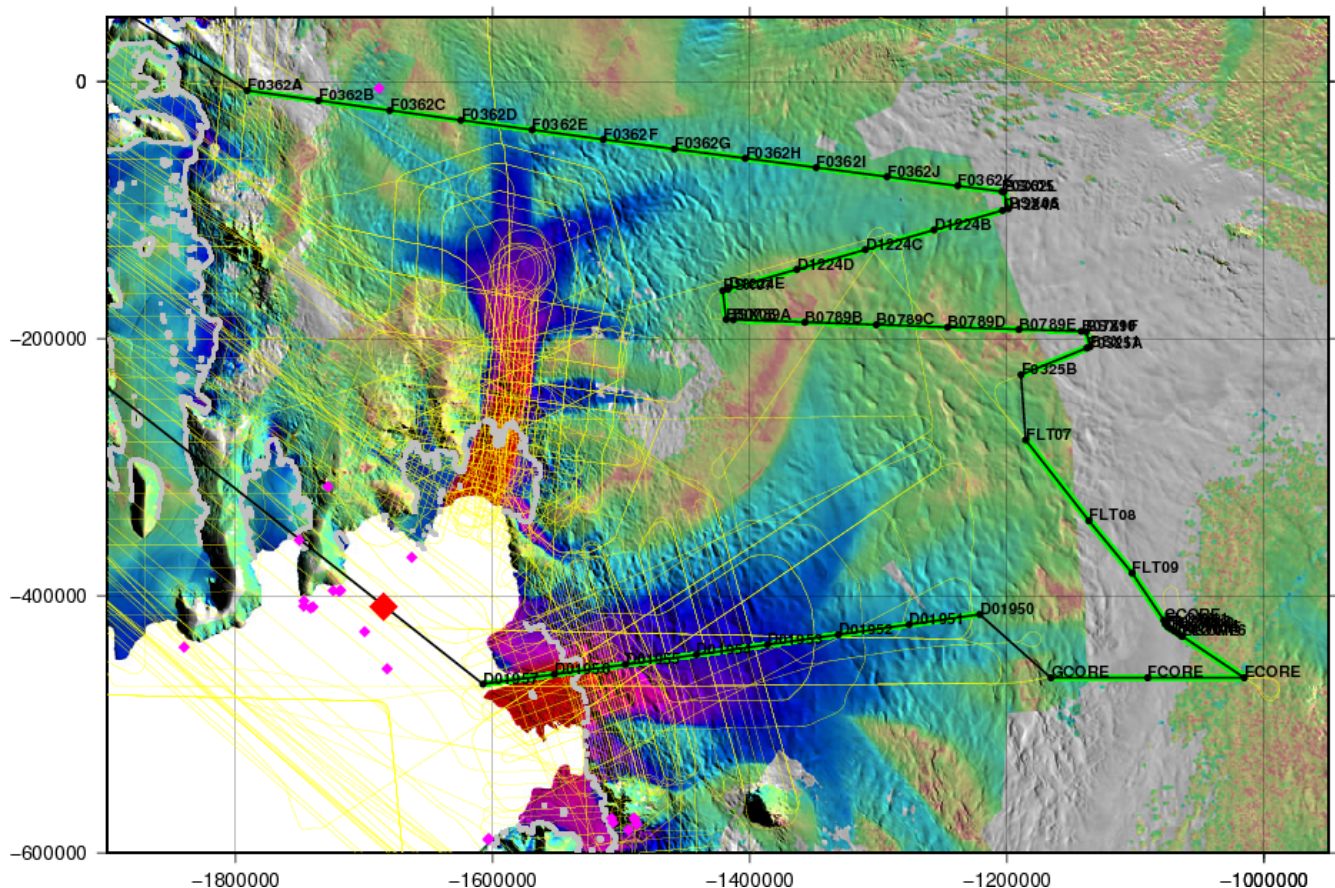
Spacecraft Tracks: F0362,D1224,B0789,F0325,D0195 (all ICESat-2)

Last Flown: 2016

Remaining Design Issues: none

IceSat-2 WAIS Cores

11.3 hours total / 4.8 hrs survey
440 knots transit / 250 knots survey



Land Ice – Low-Latency Lower PIG IS-2

This is a new mission, designed to cross the lower Pine Island Glacier channel along ICESat-2 lines multiple times with low time separation between OIB and IS-2 passes. For these tracks, we specifically target the strong beam of each beam pair.

Flight Priority: BASELINE

ICESat-2 latency: short

Science Requirements Addressed: P1,P2,P3,IS6,IS7,IS10,IS12,IS13

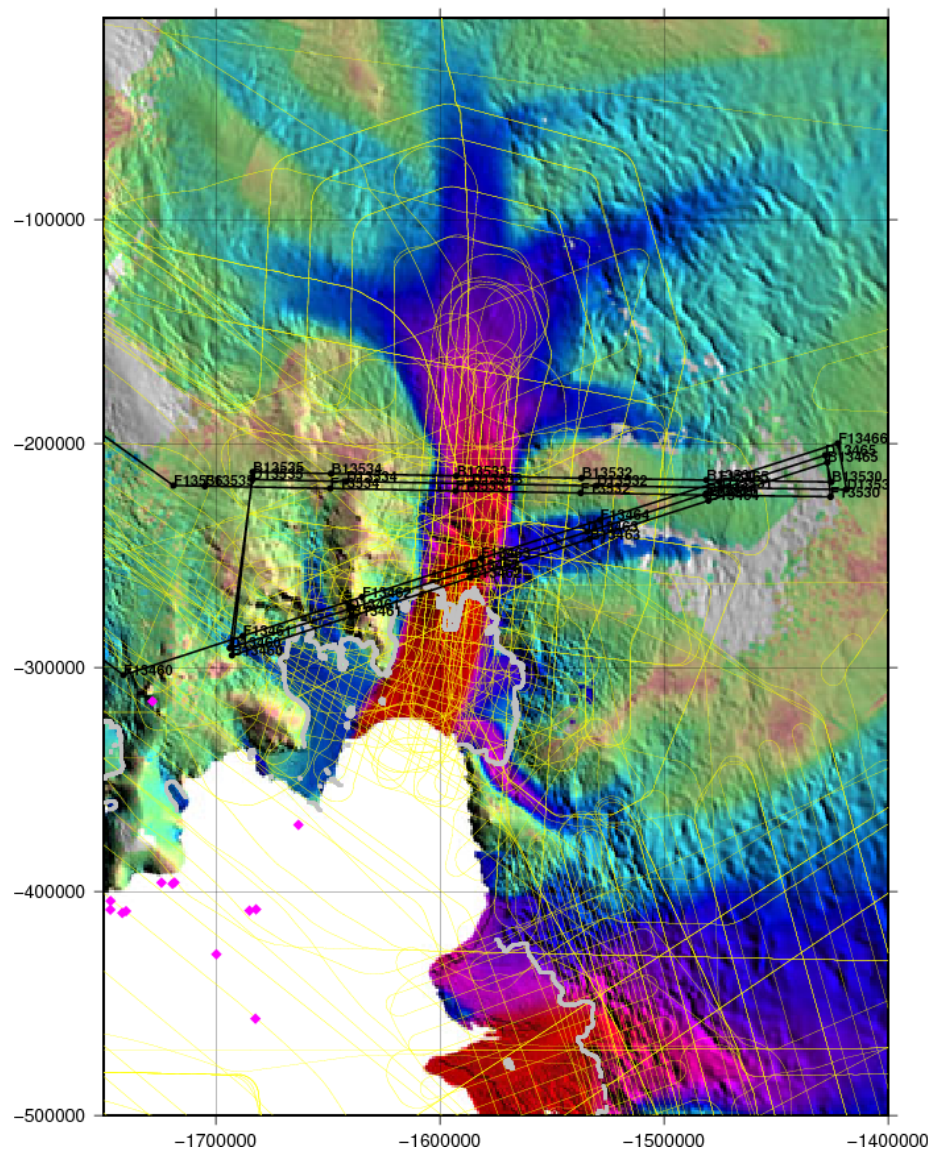
Spacecraft Tracks: F1346,D1353,D1346,B1353,B1346,F1353 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Low-Latency Lower PIG IS-2

11.2 hours total / 4.7 hrs survey
440 knots transit / 250 knots survey



Land Ice – PIG Arch IS-2

This new mission is designed to sample roughly the same area as the older PIG Arch mission, but along ICESat-2 ground tracks.

Flight Priority: low

ICESat-2 latency: short

Science Requirements Addressed: P1,P2,P4,IS12,IS13

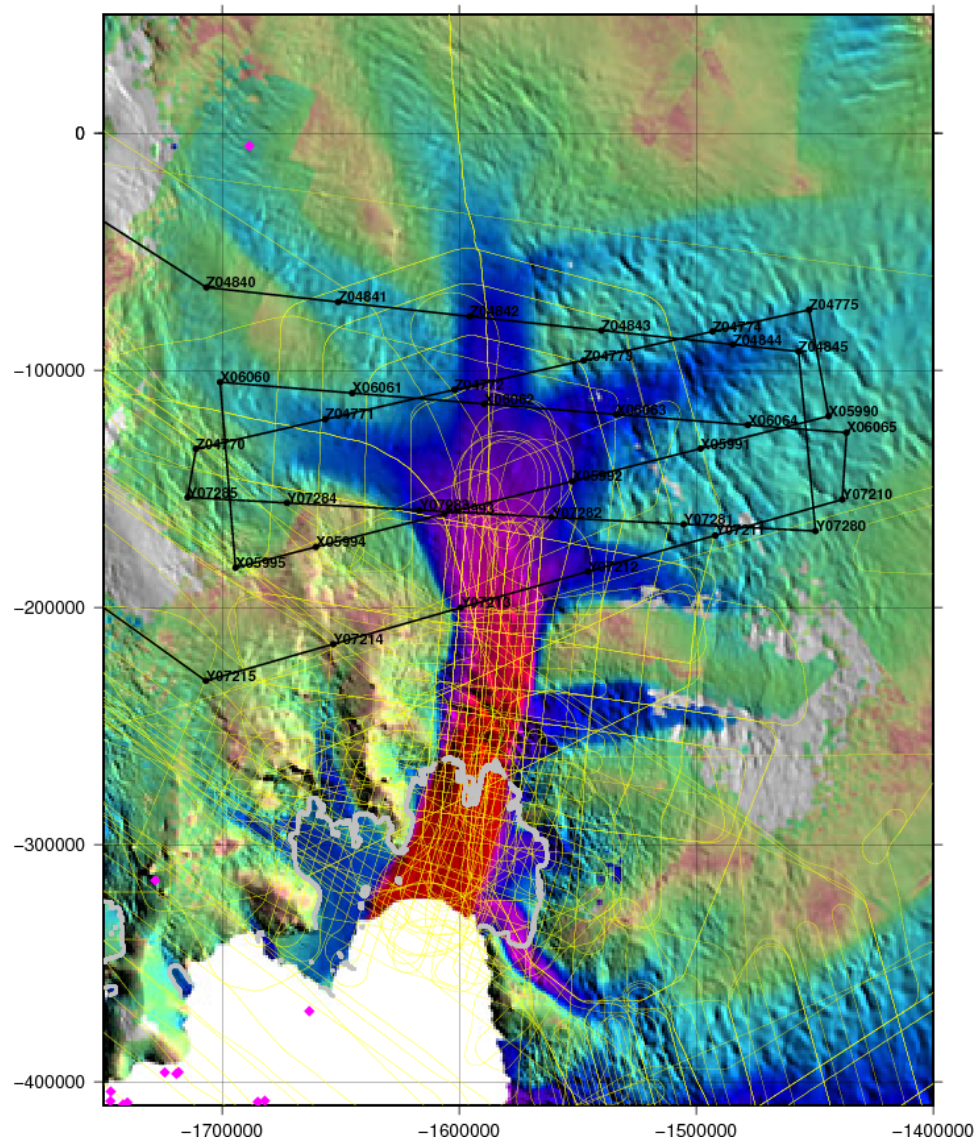
Spacecraft Tracks: Z0484,Y0728,Z0477,X0599,X0606,Y0721 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

PIG Arch IS-2

10.9 hours total / 4.5 hrs survey
440 knots transit / 250 knots survey



Land Ice – Pine Island 5

This flight is primarily derived from the eastern portion of the 2012 PTSK High-Altitude flight, whose lines were themselves derived from 2009 LVIS lines over the main Pine Island Glacier trunk. The mission is designed to collect dh/dt measurements over this area. We supplement these lines with segments from the 2002-2009 NASA-Chilean and OIB lines over several of the tributary channels feeding the main channel.

Flight Priority: BASELINE (multi-year repeat flight)

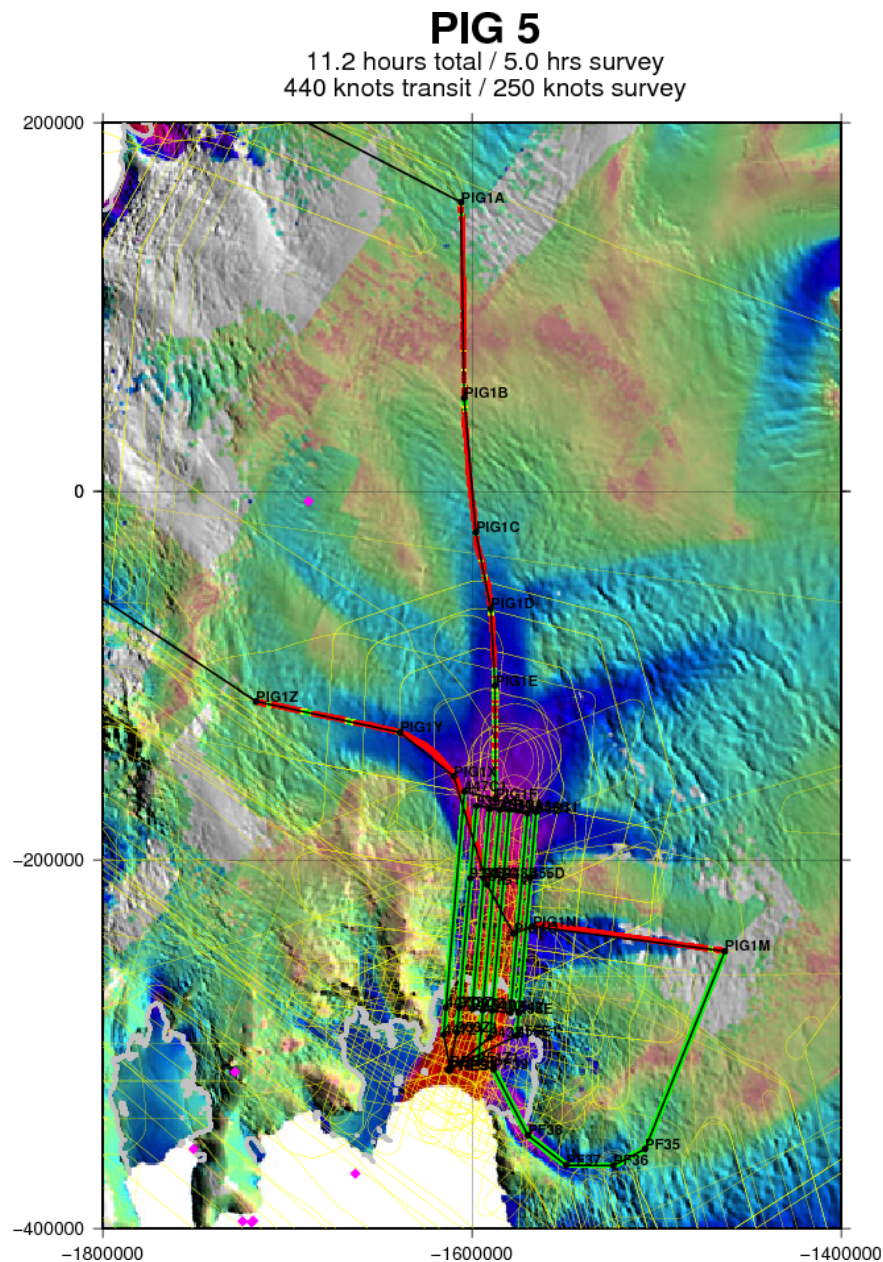
ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: none

Last Flown: 2016

Remaining Design Issues: none



Land Ice – Ferrigno-Alison-Abbott 01

This flight is designed to collect dh/dt measurements on established OIB flight lines along the coast near the Ferrigno and Alison ice streams. For 2018 we replace the lines on the Abbott Ice Shelf with new segments intended to fill two coverage gaps identified by Romain Millain, one on the outboard edge of the northeastern part of the shelf, and the other on its west end.

Flight Priority: low (multi-year repeat flight)

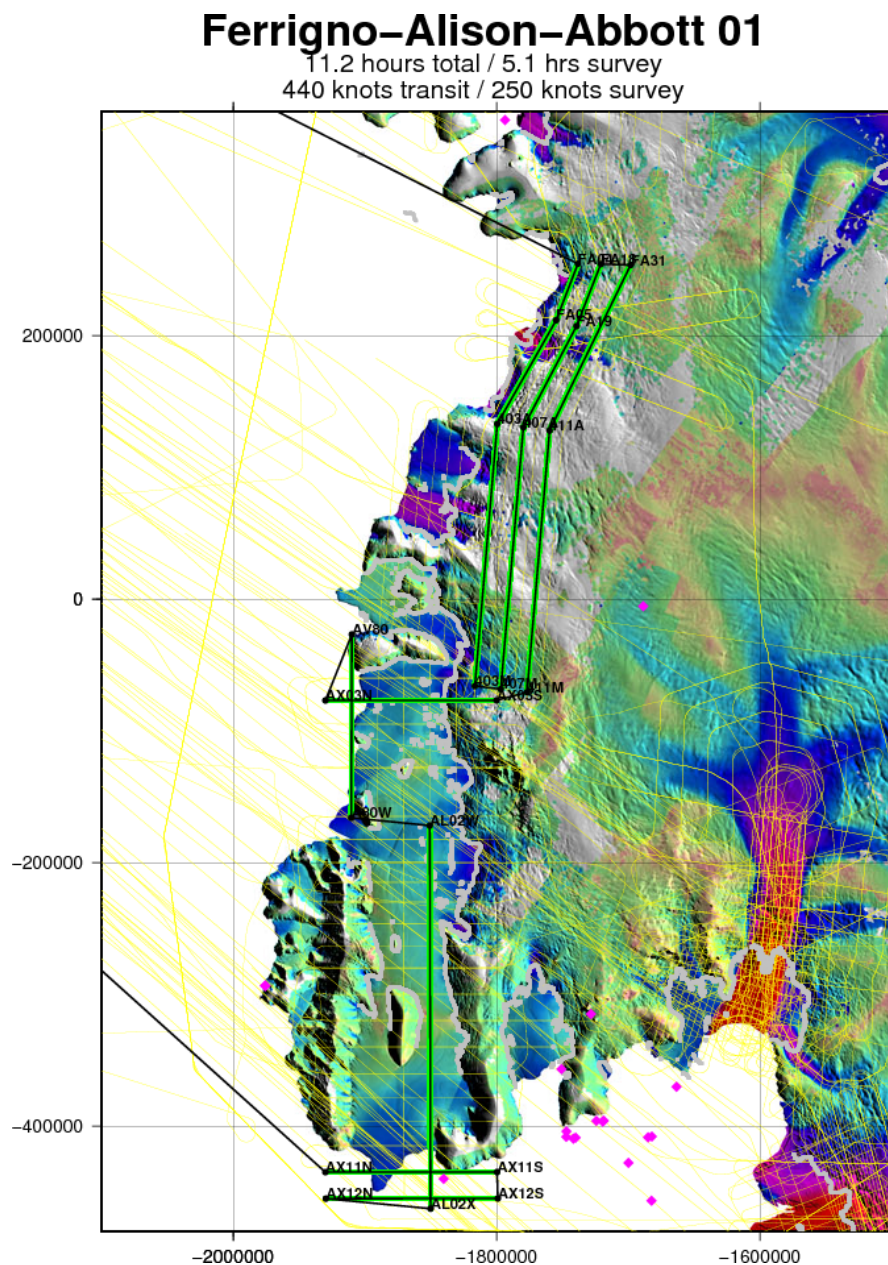
ICESat-2 latency: n/a

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: none

Last Flown: 2014, portions of Ferrigno-Alison segment in 2017

Remaining Design Issues: none



Land Ice – Bellingshausen-Amundsen Divide IS-2

This new mission is designed to sample the area of the Bryan Coast and inland, include PIG drainage to the Amundsen Sea and Evans drainage to the Weddell, all along ICESat-2 ground tracks. It also overflies two ice cores sites known as “Bryan” and “Ferrigno”.

Flight Priority: medium

ICESat-2 latency: short

Science Requirements Addressed: P1,P2,P3,P4,IS10,IS12

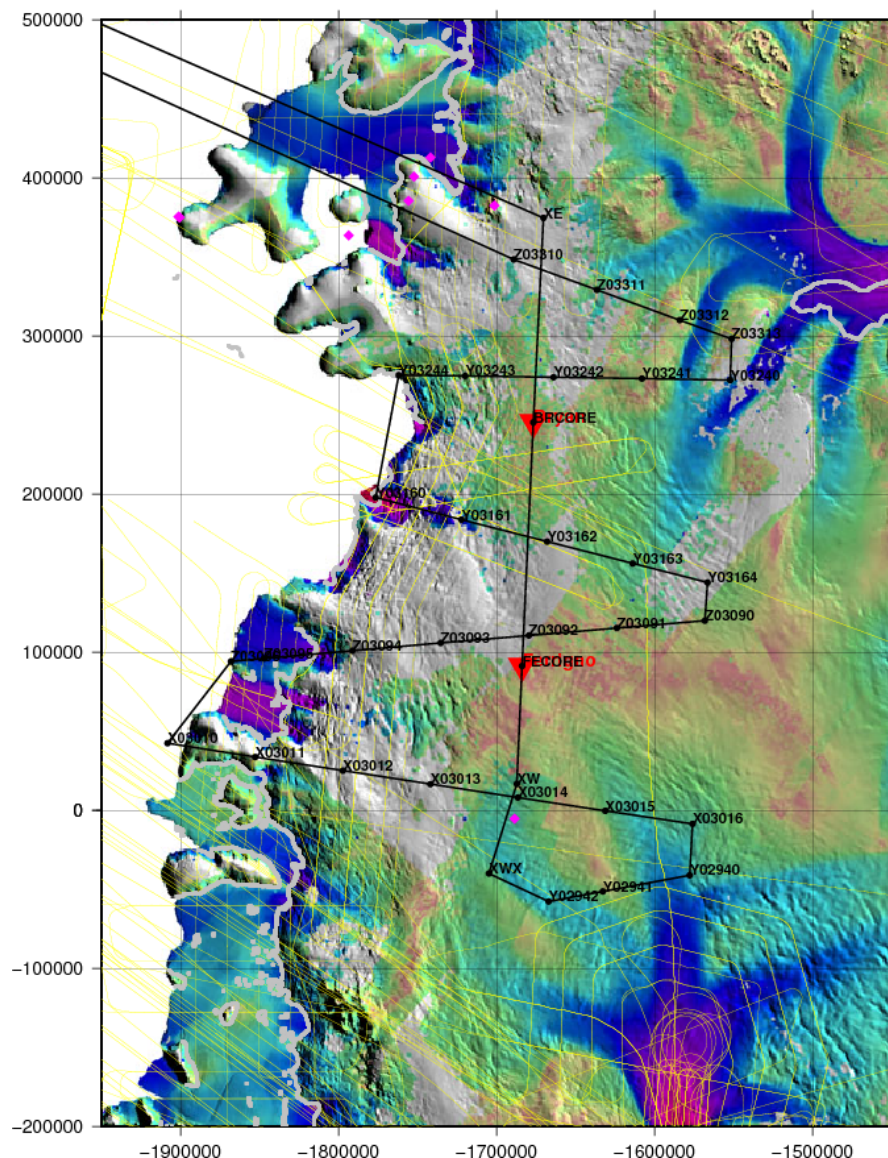
Spacecraft Tracks: Z0331,Y0324,Y0316,Y0309,Y0301,Y0394 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Bell-Amundsen Divide IS-2

10.7 hours total / 4.8 hrs survey
440 knots transit / 250 knots survey



Land Ice – North Peninsula IS-2

This is a repeat flight, designed to assess dh/dt of several glaciers draining into the Larsen-A, -B, and -C embayments. From north to south, these glaciers are the Drygalski, Hektoria, Crane, Melville, Starbuck, Flask, Leppard, Attlee, Gould, Demorest, Gibbs, and Weyerhauser. In addition to these glaciers, we repeat two lines over Scar Inlet, several flowlines on the Larsen-C Ice Shelf, and four north-south tie lines over the Larsen-C, including overflights of three AWS stations and several areas of stagnant ice so that contributions of surface processes to dh/dt can be assessed independently of dynamic processes. Finally we overfly the Gipps (in the south) and Bawden (north) Ice Rises on the eastern edge of the Larsen-C, since these may contribute to the stability of the ice shelf. Ensure Headwall is recording from ATLE1 to L096, from DRYB to LEPM1, and from WEYRD to AKNA2.

Flight Priority: BASELINE (multi-year repeat flight)

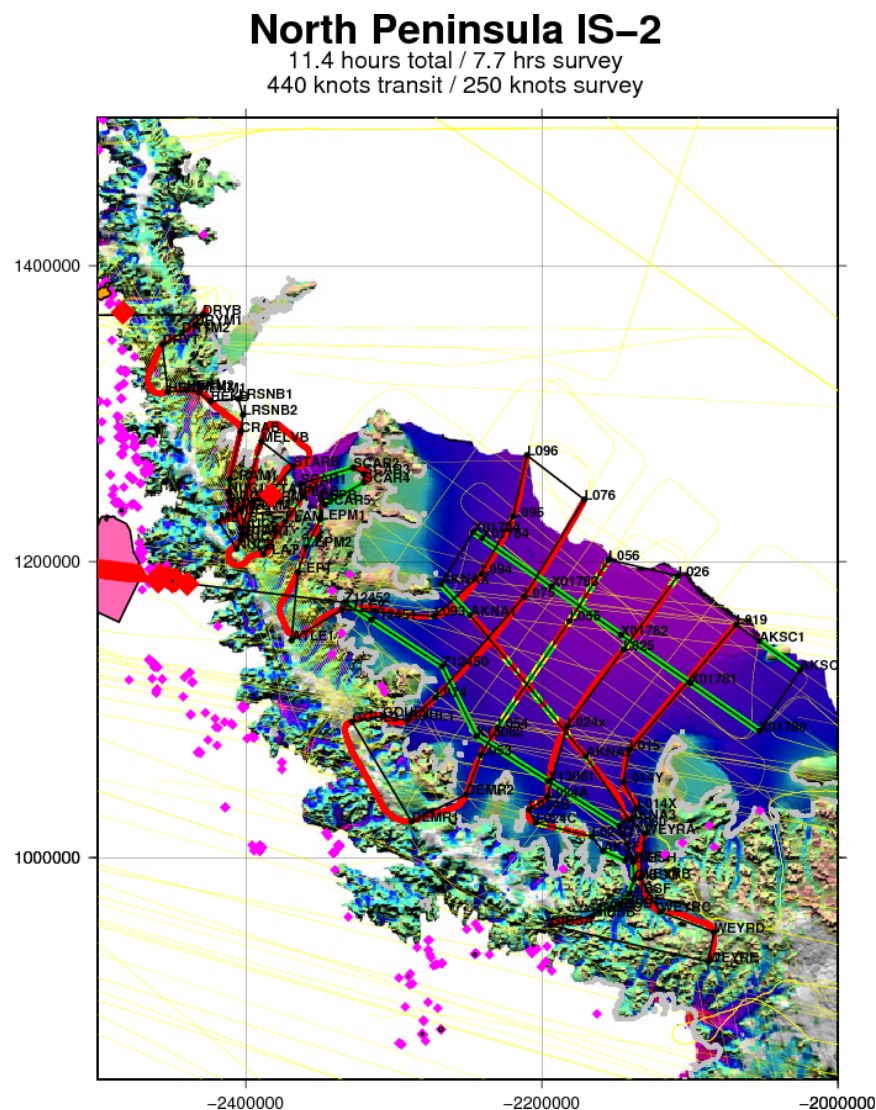
ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: X0178,X1306,Z1245 (all ICESat-2)

Last Flown: 2016 and portions in 2017

Remaining Design Issues: none



Land Ice – Larsen-C Grounding Zone IS-2

This new flight surveys the upper portion of the Larsen-C ice shelf along ICESat-2 ground tracks. We specifically target the strong beam of each ICESat-2 beam pair for this mission. Ensure Headwall is recording between D03000-D03001, F12454-F12455, F08030-F08031, F03614-F03616, F08034-F08035, F03610-F03611, and F08643-F08644.

Flight Priority: medium

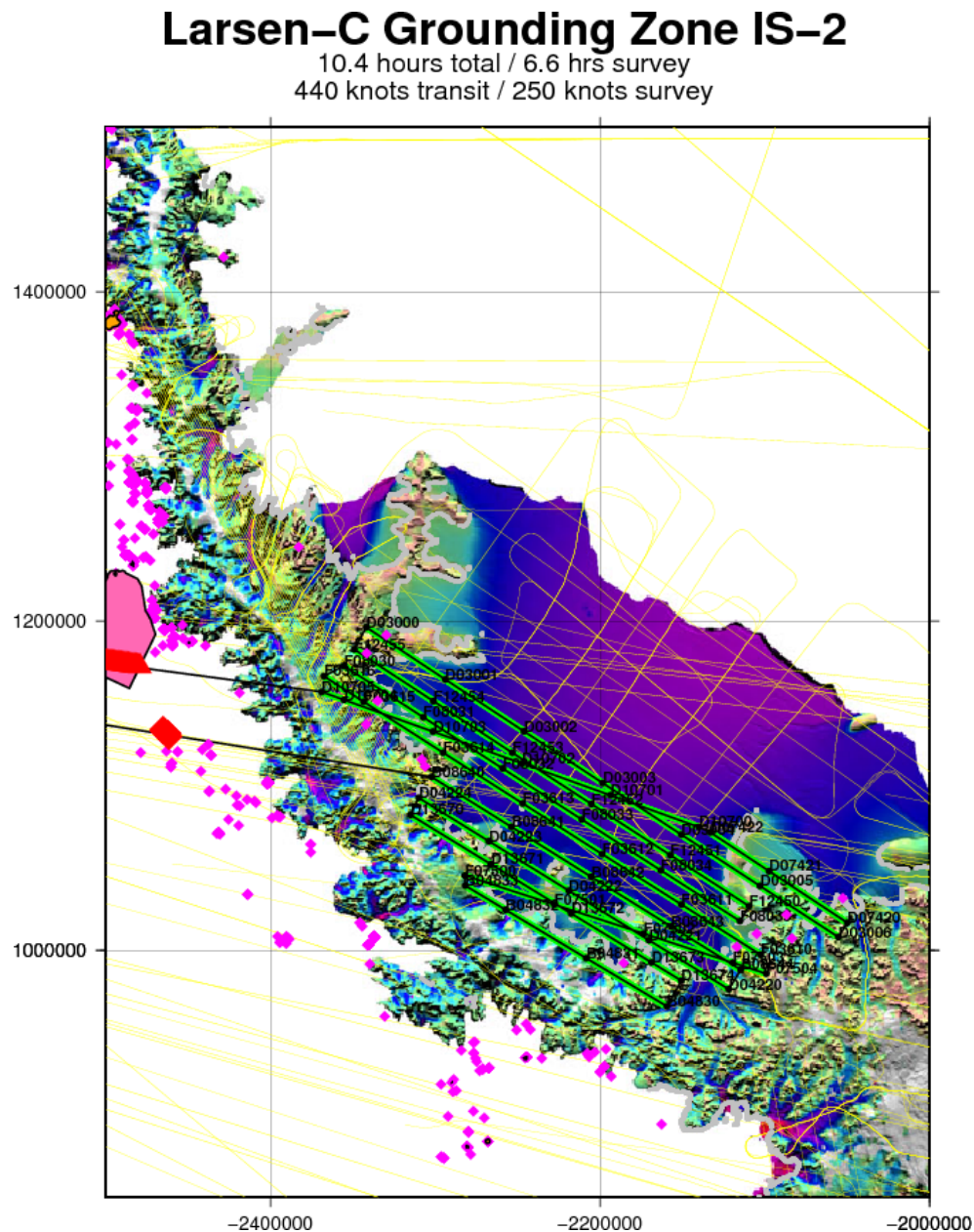
ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P3,P4,IS6,IS7,IS11,IS12,IS13

Spacecraft Tracks: B0864,D0422,D1367,D0483,F07500,F0361,F0803,F1245,D0300,D0742,D1070 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none



Land Ice – South Peninsula IS-2

This is a repeat flight, designed to assess dh/dt of four glaciers draining the Dyer Plateau. These are the Fleming, Maitland, Lurabee, and Clifford. We also re-fly a portion of the grounding line along the George VI Ice Shelf, which was last flown in 2011. For 2018 we replace a coast-parallel grid along the western flank of the Dyer Plateau with a similar grid of ICESat-2 ground tracks. We also fly a pair of lines across the northern edge of the George VI ice shelf, primarily to fill a small gap in gravity measurements there. The Fleming Glacier lines in this mission are supplemented by a 10 km grid over Fleming in the Alexander-Fleming flight. Ensure Headwall is recording between X09940-X09943, X04910-X04914, GVI5EN-GVI5ES, and GVI5WN-GVI5WS.

Flight Priority: BASELINE (multi-year repeat flight)

ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

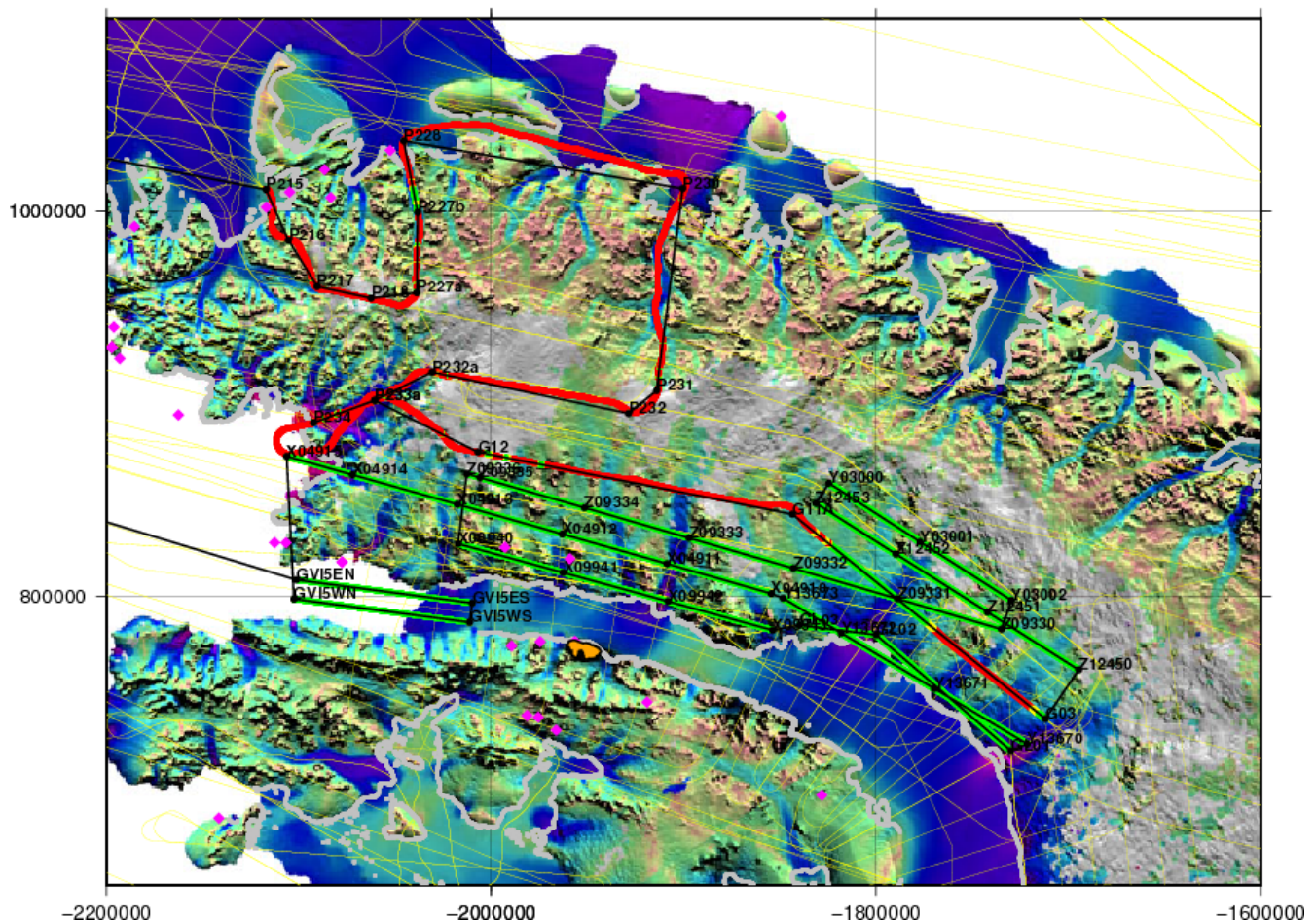
Spacecraft Tracks: Z1245,Y0300,Z0933,X0994,Y1367,X0491 (all ICESat-2)

Last Flown: 2017

Remaining Design Issues: none

South Peninsula IS-2

11.1 hours total / 6.7 hrs survey
440 knots transit / 250 knots survey



Land Ice – Larsen D IS-2

This is a new flight, designed to supplement the bedrock and gravity measurements from the previous “Larsen-D 01” OIB flight with interlaced lines along ICESat-2 (nadir beam pair) ground tracks. In addition to the ascending and descending ICESat-2 tracks, we also fly tie lines in the north and south, to assist in gravity recovery. Ensure Headwall is recording between Y09487-Y09480, Y13216-Y13211, and Y00641-Y00645.

Flight Priority: low

ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

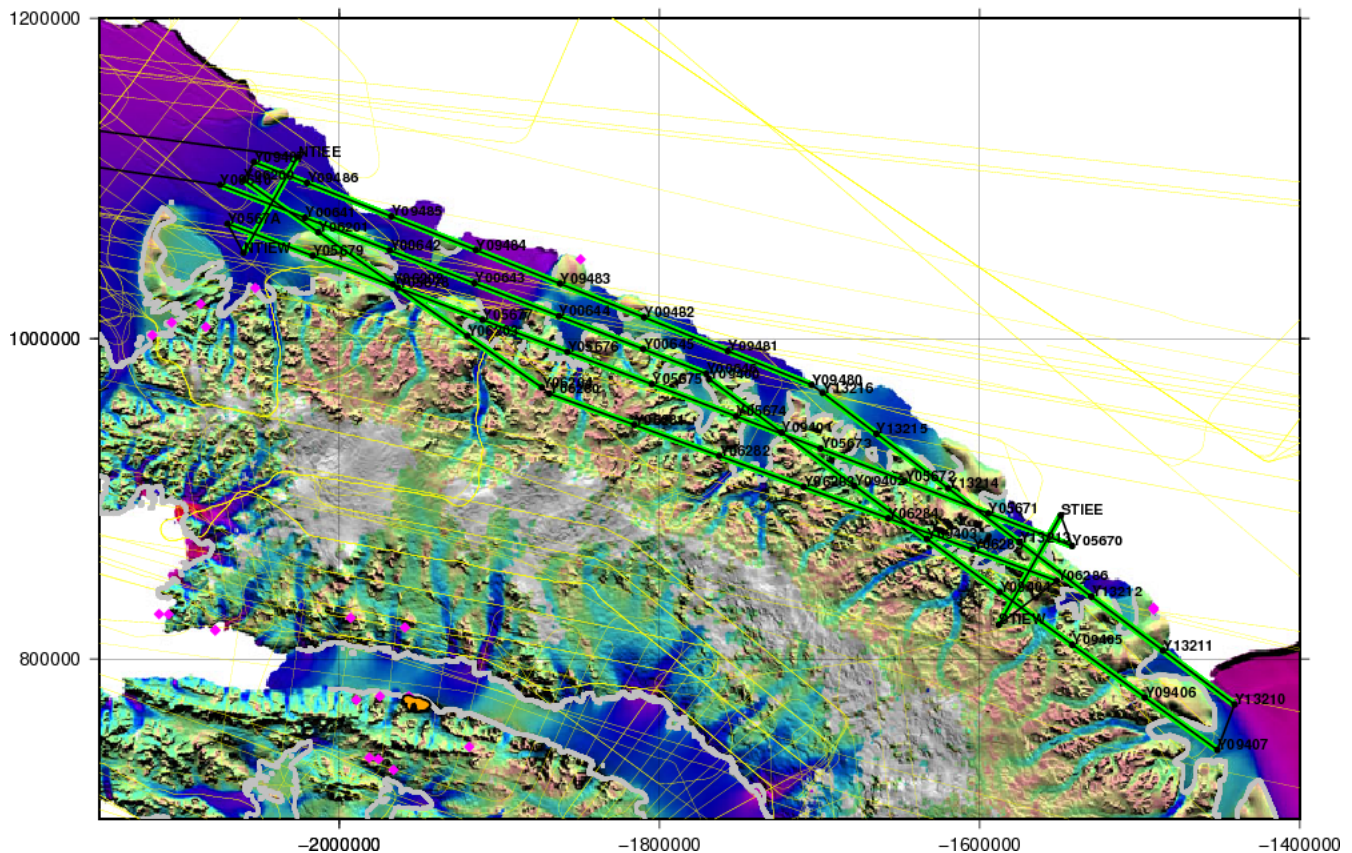
Spacecraft Tracks: Y0064,Y0940,Y1321,Y0948,Y0620,Y0628,Y0567 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Larsen-D IS-2

11.1 hours total / 6.6 hrs survey
440 knots transit / 250 knots survey



Land Ice – Evans IS-2

This new flight is designed to survey the Evans Ice Stream, mostly along ICESat-2 ground tracks. It also reflies a centerline of the ice stream, flown only once by OIB in 2009.

Flight Priority: low

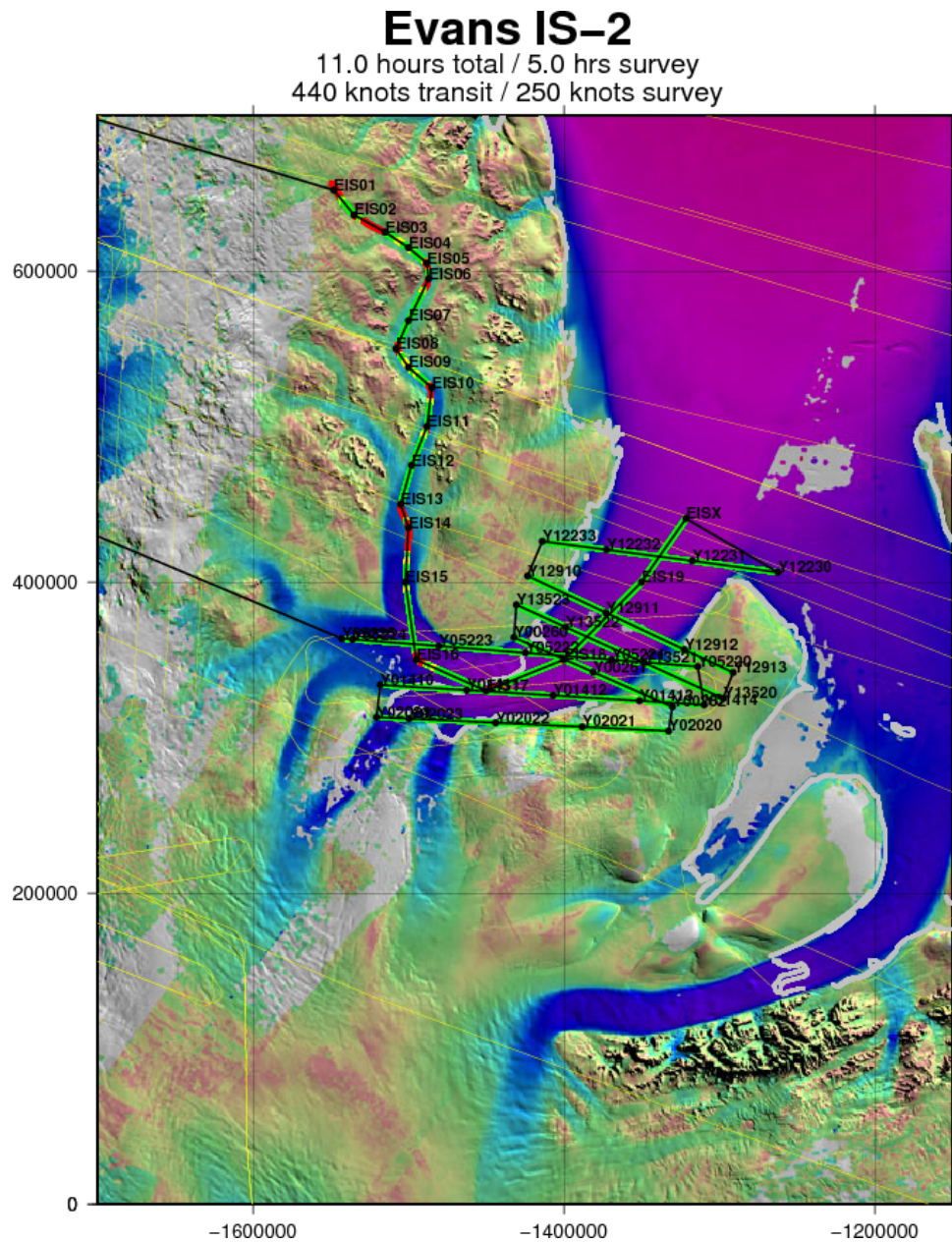
ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS6,IS7,IS11,IS12,IS13

Spacecraft Tracks: Y1223,Y1291,Y1352,Y0026,Y0202,Y0141,Y0522 (all ICESat-2)

Last Flown: portions in 2009

Remaining Design Issues: none



Land Ice – Institute IS-2

This flight is designed to survey the lower Institute Ice Stream along ICESat-2 ground tracks.

Flight Priority: medium

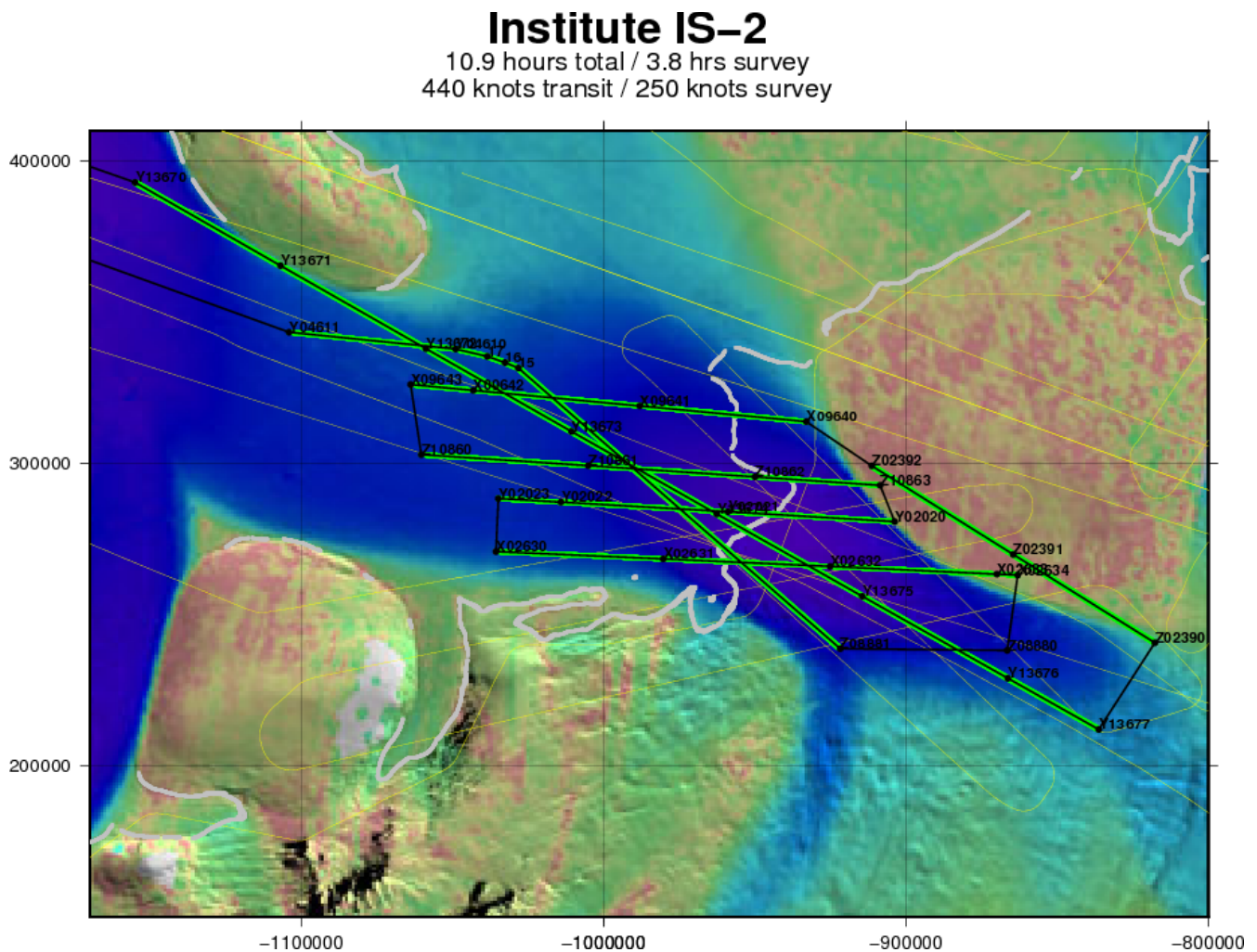
ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS6,IS7,IS11,IS12,IS13

Spacecraft Tracks: Y1367,Z0239,X0964,Z1086,Y0202,X0263,Z0888,Y0461 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Foundation Lakes IS-2

This flight is a dh/dt repeat of the identical 15 October 2012 flight. It occupies straightened approximations of the Foundation and Support Force ice streams, and crosses several subglacial lakes in their upper portions. Many of the original lines were redesigned for 2018 along ICESat-2 ground tracks. For these tracks, we specifically target the strong beam of the center beam pair.

Flight Priority: low (multi-year repeat flight)

ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

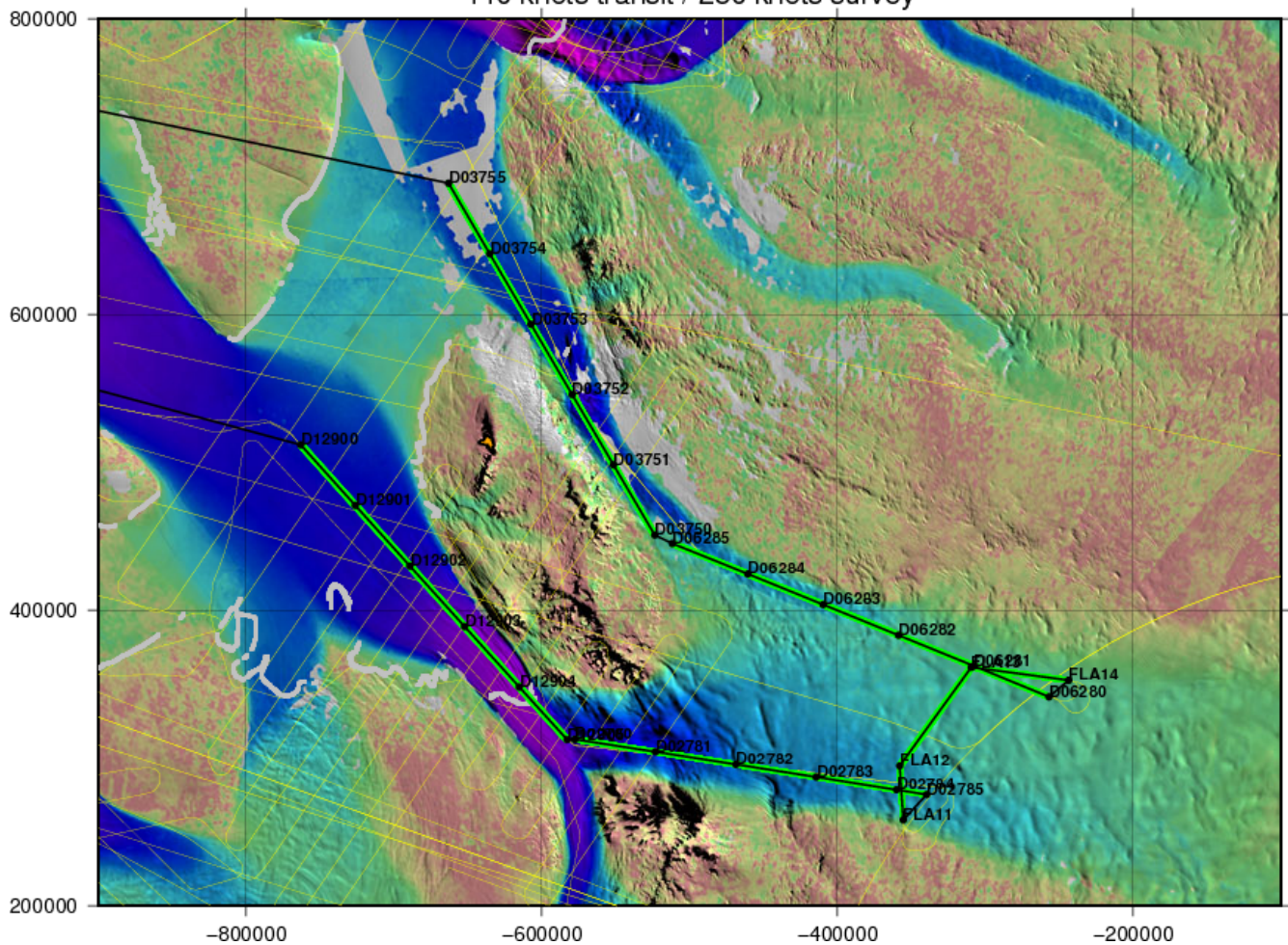
Spacecraft Tracks: D1290,D0278,D0628,D0375 (all ICESat-2)

Last Flown: 2014

Remaining Design Issues: none

Foundation Lakes IS-2

11.1 hours total / 3.1 hrs survey
440 knots transit / 250 knots survey



Land Ice – Foundation-Academy IS-2 A

This is a new flight for 2018. It flies ICESat-2 ground tracks crossing the channel of upper Foundation Ice Stream, and also over more stagnant ice on both sides of the Foundation channel. For these tracks, we specifically target the strong beam of each beam pair. We also add an overflight of a permanent GPS station known as RMBO, to assist with calibration and validation of ATM measurements.

Flight Priority: high

ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS7,IS10,IS11,IS12,IS13

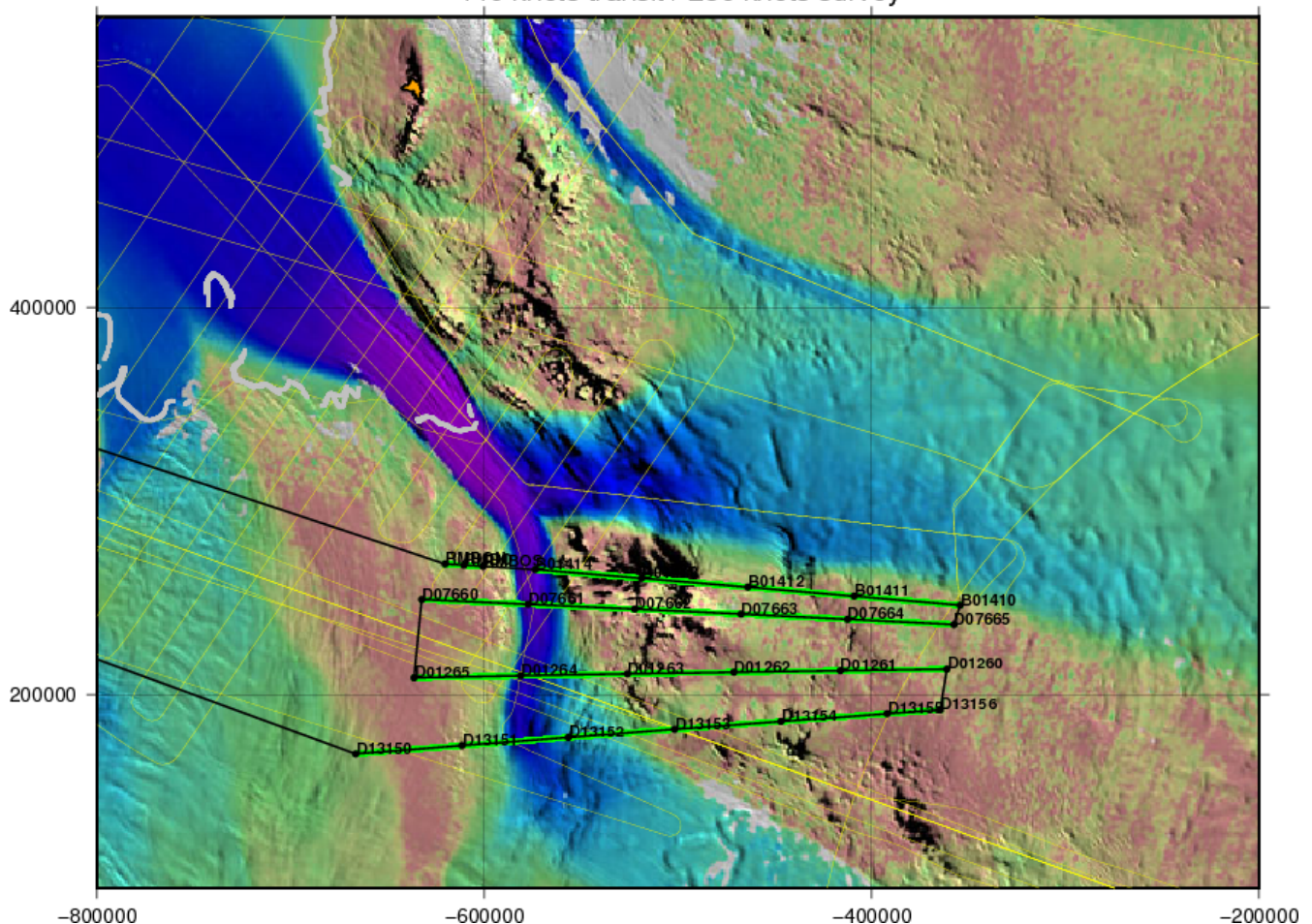
Spacecraft Tracks: D1315,D0126,D0766,B0141 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Foundation-Academy IS-2 A

11.3 hours total / 2.9 hrs survey
440 knots transit / 250 knots survey



Land Ice – Foundation-Academy IS-2 B

This is a new flight for 2018. It flies ICESat-2 ground tracks crossing the channel of Academy and Support Force Ice Streams. For these tracks, we specifically target the strong beam of each beam pair.

Flight Priority: high

ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS7,IS10,IS11,IS12,IS13

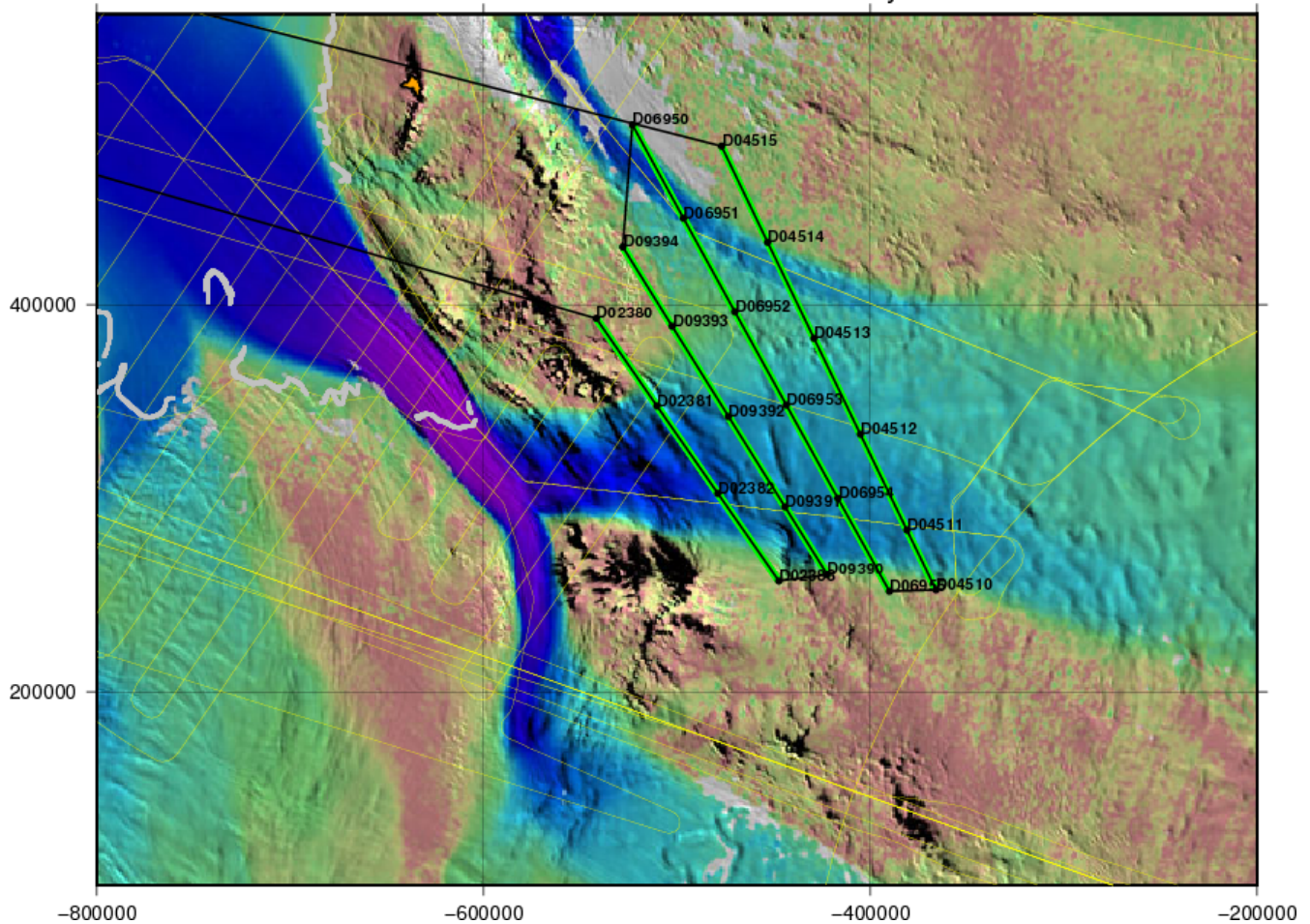
Spacecraft Tracks: D0238,D0939,D0695,D0451 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Foundation–Academy IS–2 B

11.1 hours total / 2.5 hrs survey
440 knots transit / 250 knots survey



Land Ice – Support Force-Upper Blackwall IS-2

This new flight is designed to survey the channel of Support Force and upper Blackwall Glacier, mostly along ICESat-2 ground tracks. For these tracks, we specifically target the strong beam of each beam pair. The cross-flow lines also address gaps in Bedmap-2 coverage.

Flight Priority: low

ICESat-2 latency: long

Science Requirements Addressed: P1,P2,IS6,IS7,IS11,IS12

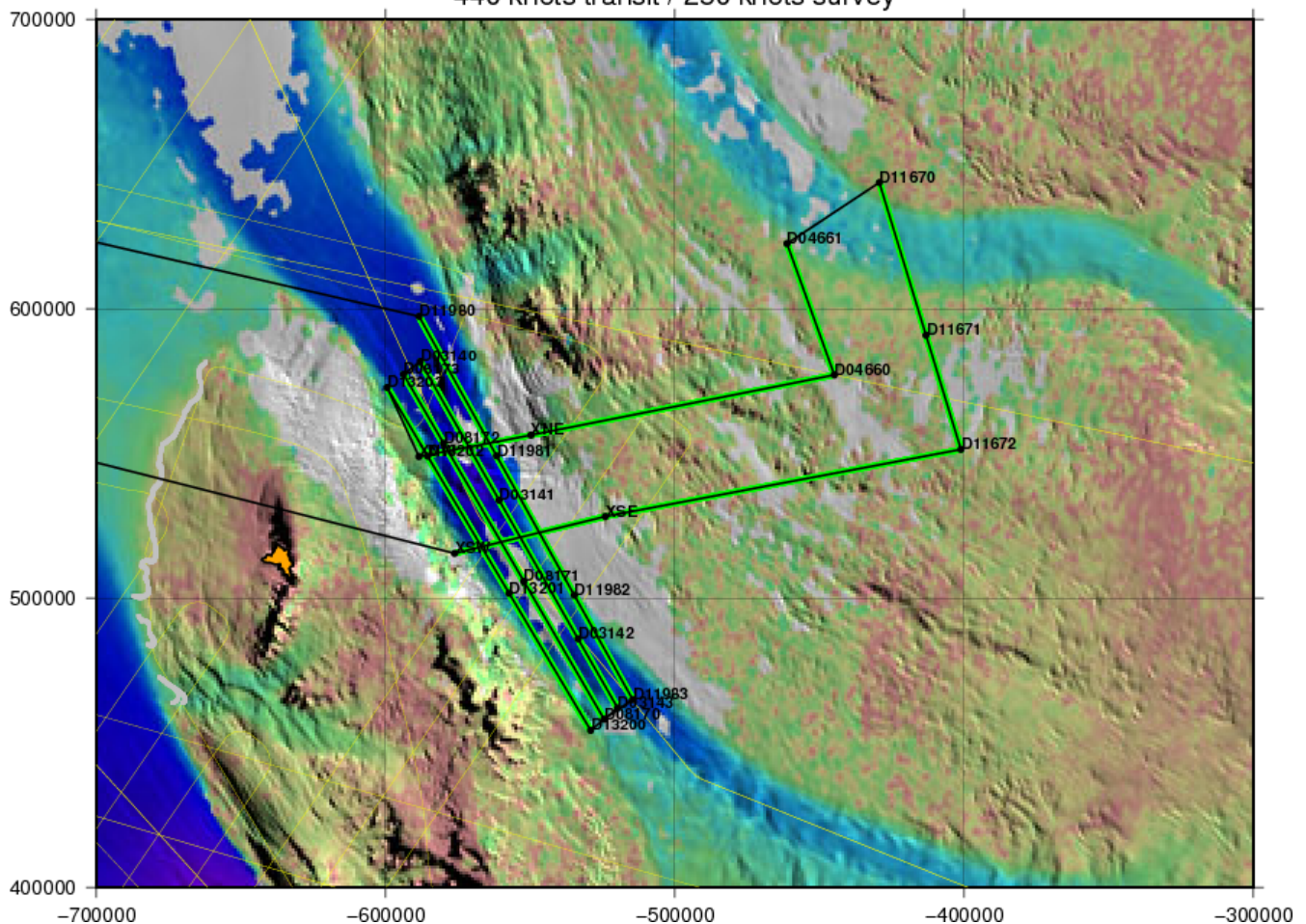
Spacecraft Tracks: D1198,D0817,D0314,D1320,D0466,D1167 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Support Force / Upper Blackwall IS-2

11.2 hours total / 2.9 hrs survey
440 knots transit / 250 knots survey



Land Ice – Blackwall-Recovery IS-2

This new flight is designed to survey the channel of Blackwell Glacier and portions of lower Recovery Glacier along ICESat-2 ground tracks. For these tracks, we specifically target the strong beam of the beam pairs, which in the case of this flight are all center beam pairs.

Flight Priority: high

ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS6,IS7,IS10,IS11,IS12,IS13

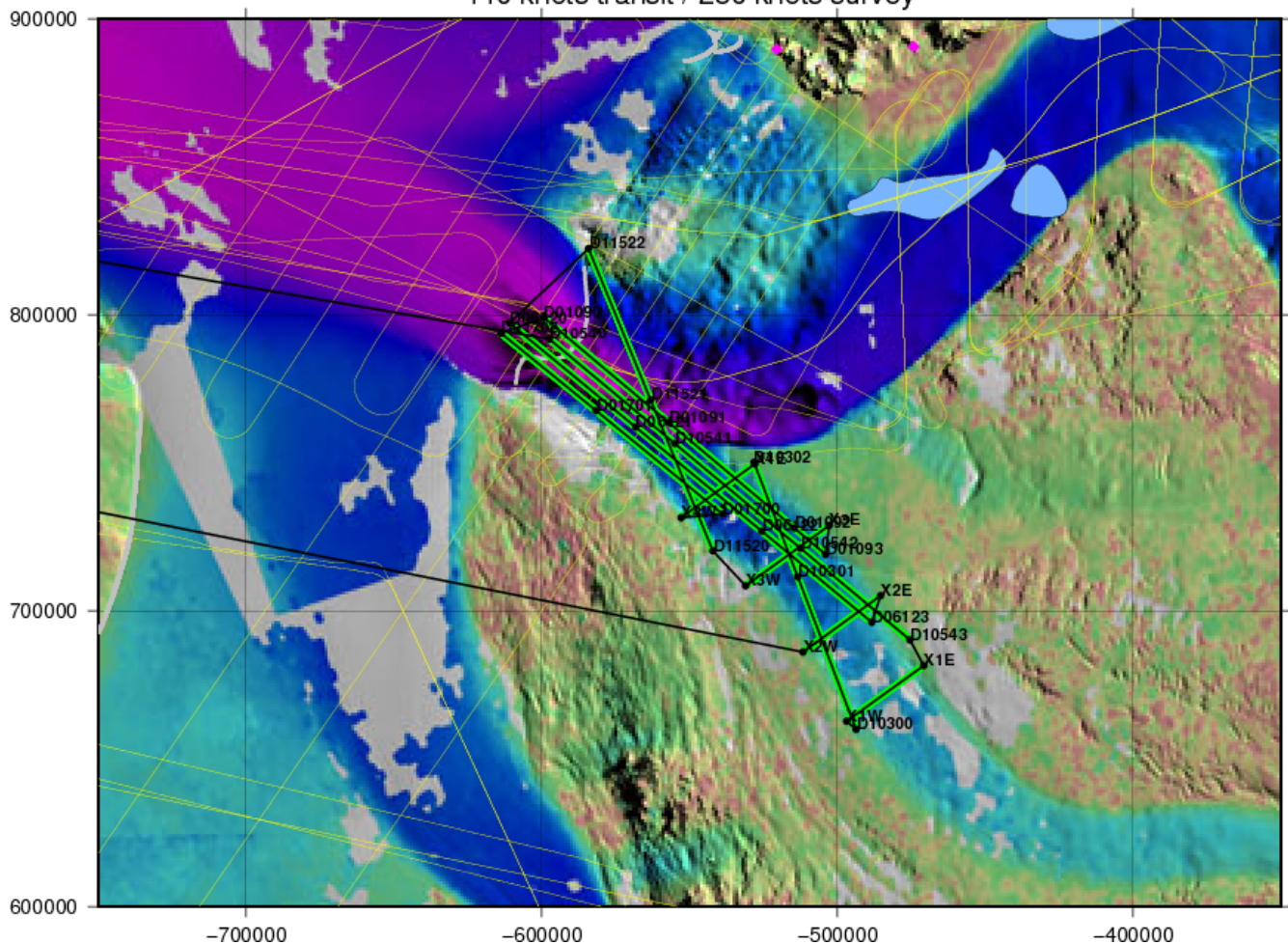
Spacecraft Tracks: D1054,D1030,D0170,D0109,D1152,D0612 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Blackwall-Recovery IS-2

11.3 hours total / 3.0 hrs survey
440 knots transit / 250 knots survey



Land Ice – Recovery IS-2

This new flight is designed to survey the channel of Recovery Glacier along ICESat-2 ground tracks. For these tracks, we specifically target the strong beam of the beam pairs.

Flight Priority: medium

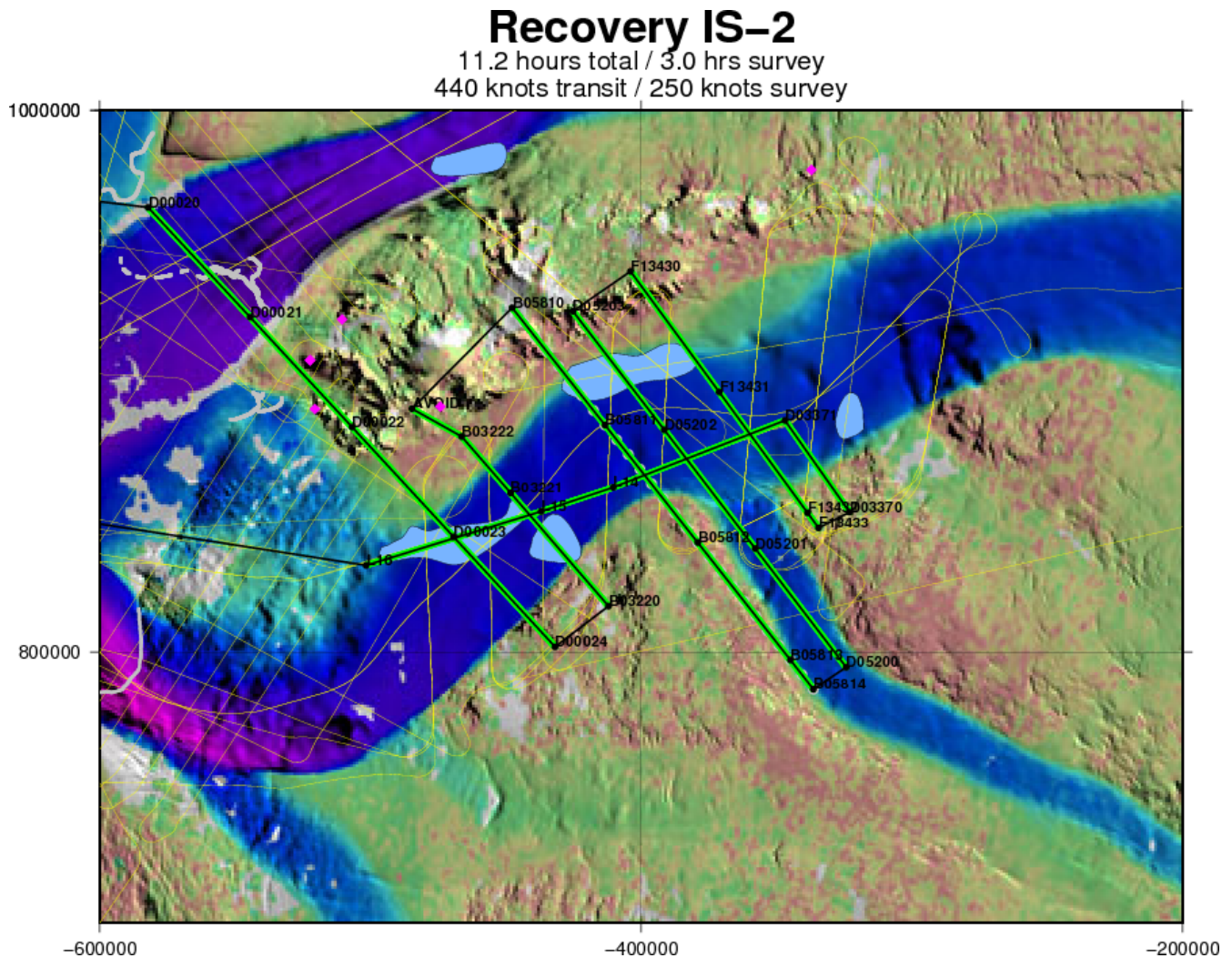
ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P3,P4,IS6,IS7,IS10,IS12,IS13

Spacecraft Tracks: D0002,B0322,B0581,D0520,F1343,D0337 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Slessor Grounding Zone/Lake IS-2

This new flight is designed to map portions of the Slessor and Bailey Glaciers, along ICESat-2 ground tracks. For these tracks, we specifically target the strong beam of the beam pairs, which in the case of this flight are all center beam pairs.

Flight Priority: high

ICESat-2 latency: long

Science Requirements Addressed: P1,P2,P4,IS6,IS7,IS11,IS12,IS13

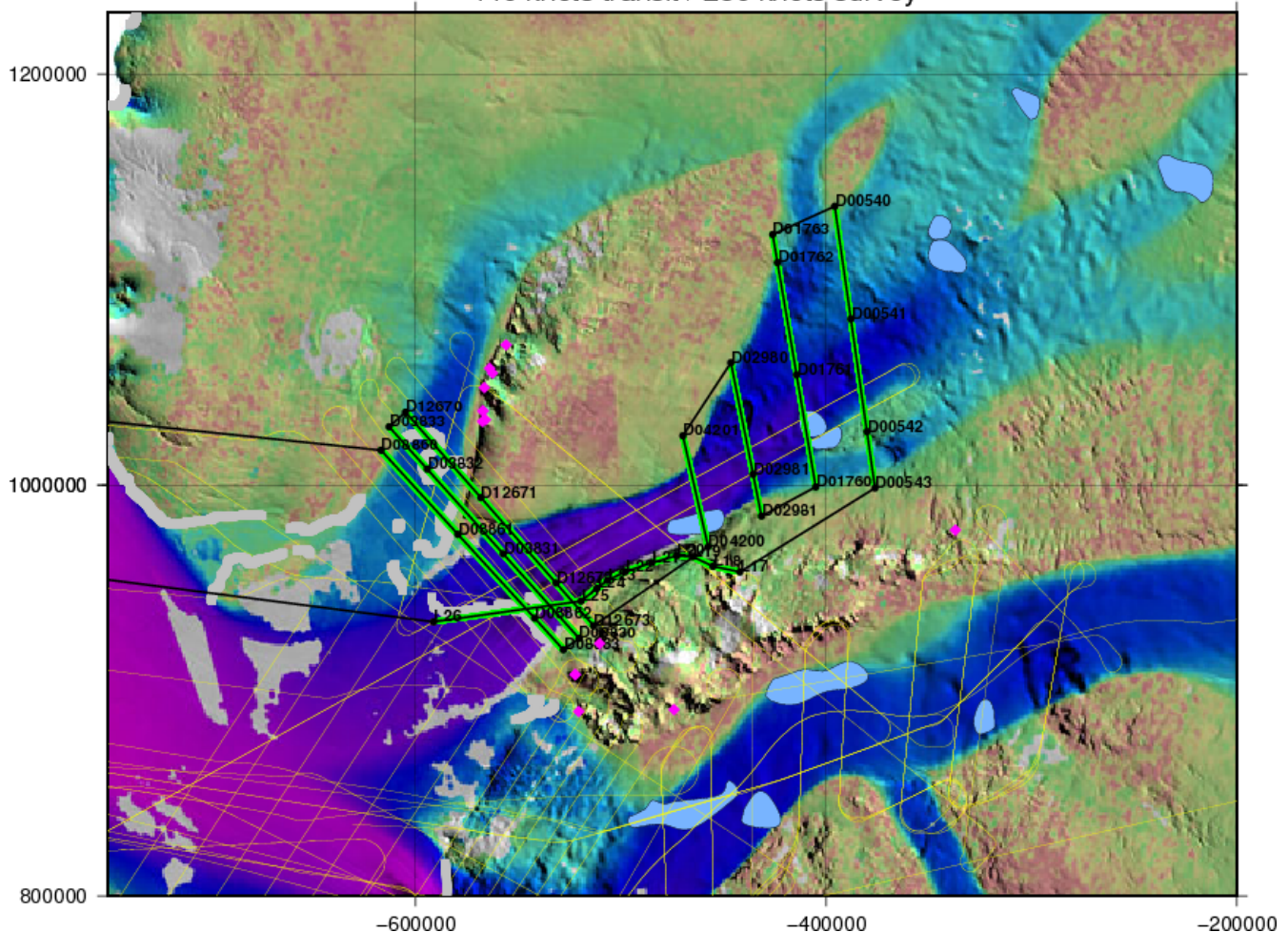
Spacecraft Tracks: D0886,D0383,D1267,D0420,D0298,D0176,D0054 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Slessor Grounding Zone/Lake IS-2

11.3 hours total / 3.2 hrs survey
440 knots transit / 250 knots survey



Land Ice – Stancomb Inshore

This new flight is designed to provides radar and lidar data along ICESat-2 ground tracks, just inshore of the grounding line across the flow of the Stancomb-Wills Glacier. This region has not been sampled by OIB prior to 2018.

Flight Priority: medium

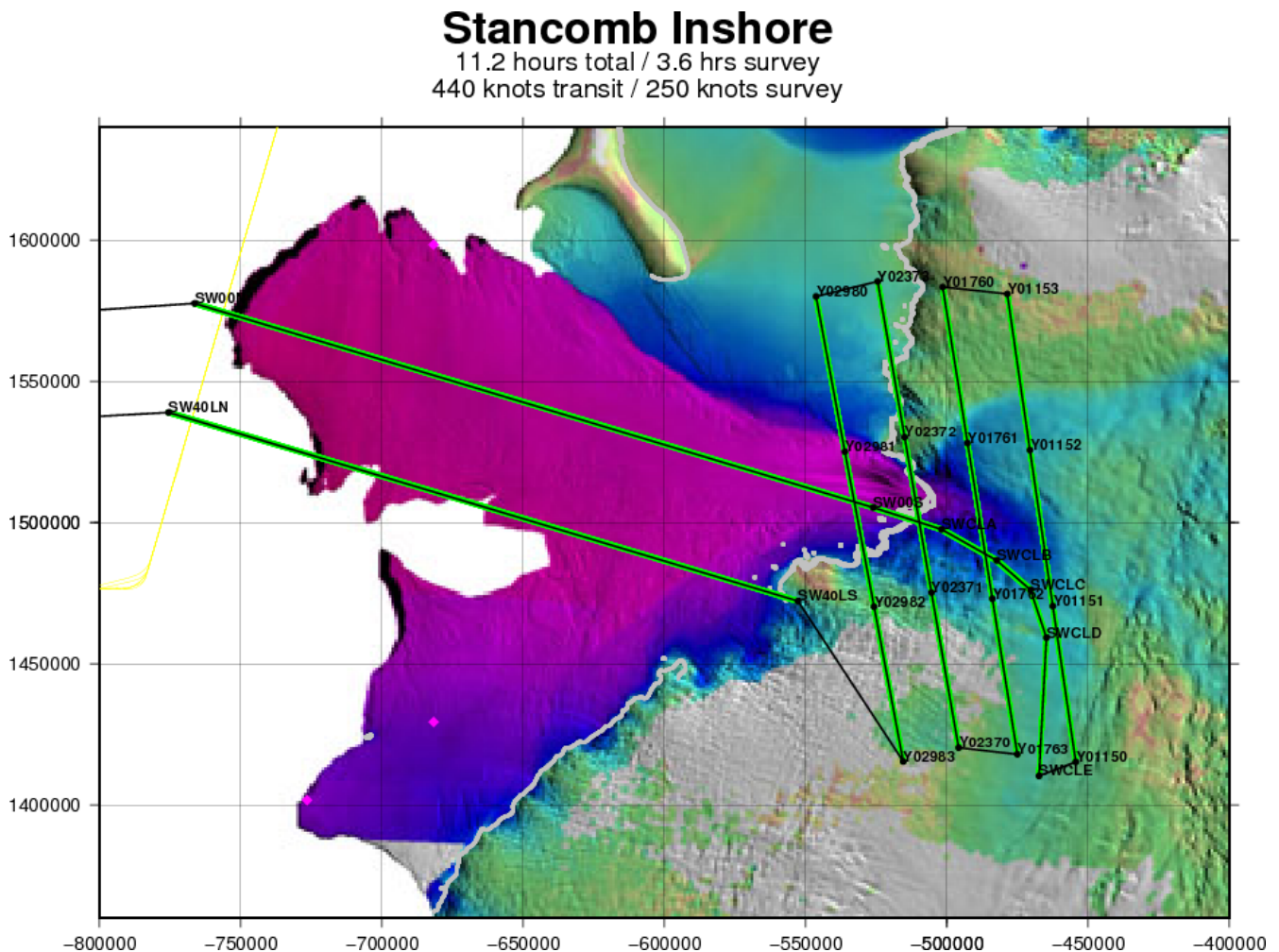
ICESat-2 latency: short

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

Spacecraft Tracks: Y0115,Y0176,Y0237,Y0298 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none



Land Ice – Stancomb Outboard

This new flight is designed to provide radar and lidar data along ICESat-2 ground tracks, mostly offshore of the grounding line of the Stancomb-Wills Glacier. This region has not been sampled by OIB prior to 2018.

Flight Priority: high

ICESat-2 latency: short

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS6,IS7,IS11,IS12,IS13,IS15

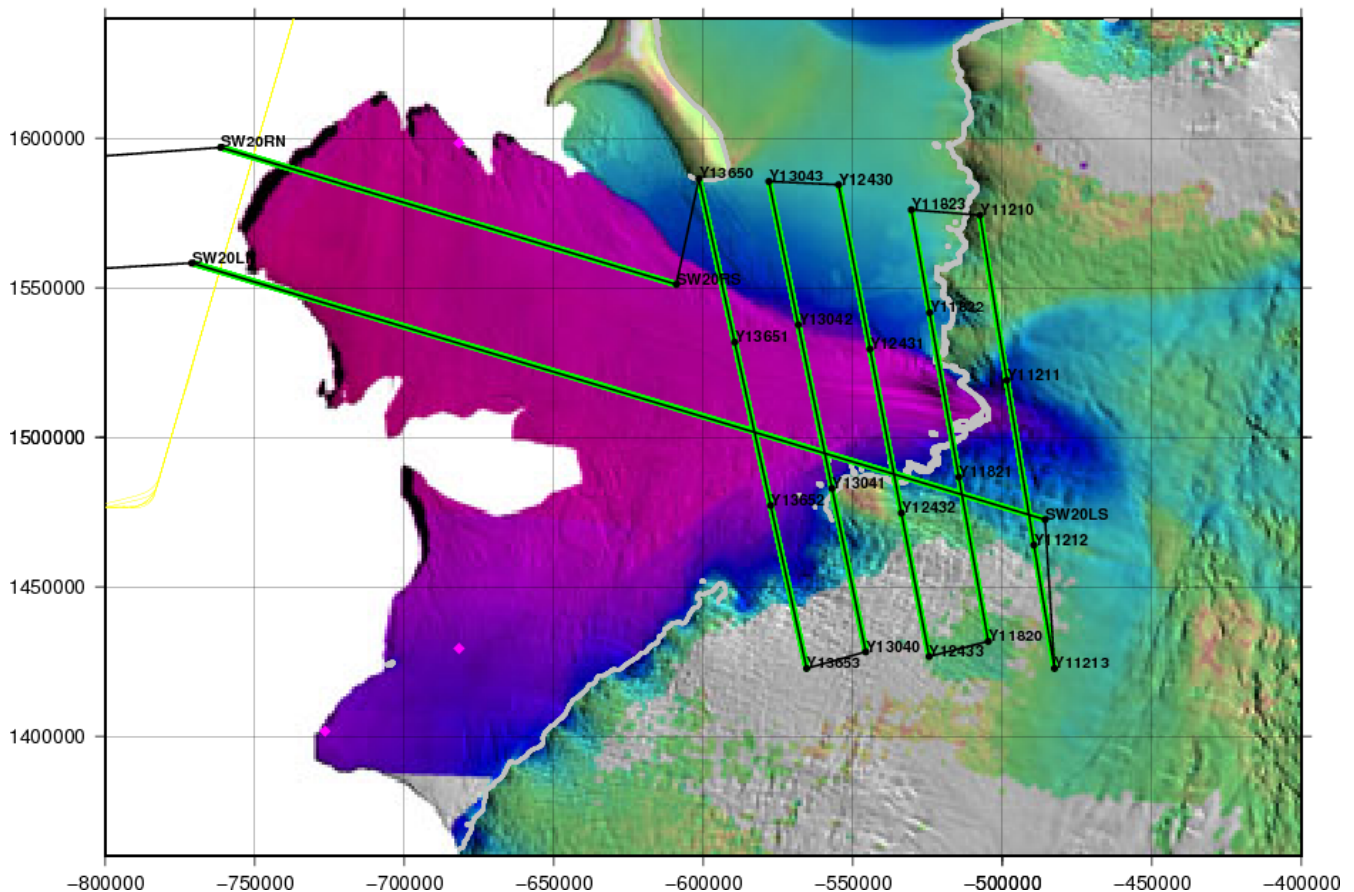
Spacecraft Tracks: Y1365,Y1304,Y1243,Y1182,Y1121 (all ICESat-2)

Last Flown: new flight

Remaining Design Issues: none

Stancomb Outboard

11.3 hours total / 3.7 hrs survey
440 knots transit / 250 knots survey



Land Ice – Long Line IS-2

This is a new flight, designed to sample a single ICESat-2 ground track on the West Antarctic Ice Sheet from the Bellingshausen Coast to high on the plateau. This area has been selected to minimize the influence of surface roughness, surface slope, and elevation change on the measurements, and should provide the best estimate of instrumental biases under ideal conditions. We fly back and forth along the left and right beam pair centerlines, with crossovers centered on the center beam pair roughly every 100 km.

Flight Priority: high

ICESat-2 latency: short

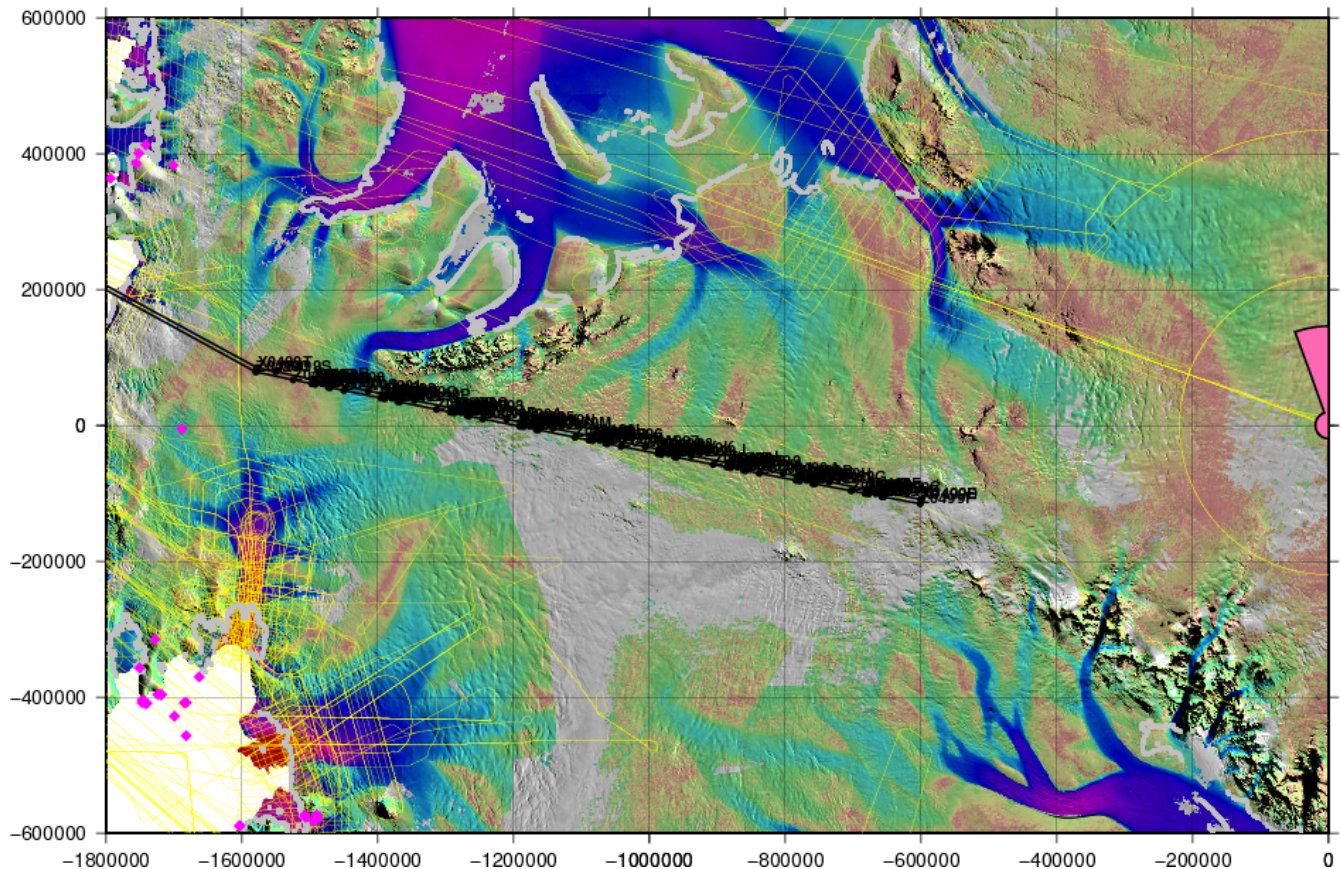
Science Requirements Addressed: none

Spacecraft Tracks: 0499 (ICESat-2)

Last Flown: new flight

Remaining Design Issues: none; use the *makelongline* script to generate the waypoints automatically

Long Line IS-2
10.9 hours total / 4.5 hrs survey
440 knots transit / 250 knots survey



Land Ice – Hamilton Line – Amery Sector

This flight's purpose is to sample the surface topography at the southern apex of many ICESat-II orbits. Specifically this flight samples the ground tracks on the Amery Ice Shelf sector of the Polar plateau. In this way, we can provide “ground truth” for every ICESat-II orbit with just three flights. The vertical stability of the surface must also be quantified for this approach to succeed, and this flight provides a repeat measurement for this purpose. This flight provides 40 km of overlap with each adjacent Hamilton Line mission. Finally, we fly a short crossover line in the overlapped section with the Hamilton Line – Ronne Sector mission. It is flown in a clockwise direction. Renamed in 2016 in honor of Dr. Gordon Hamilton.

Flight Priority: high (multi-year repeat flight)

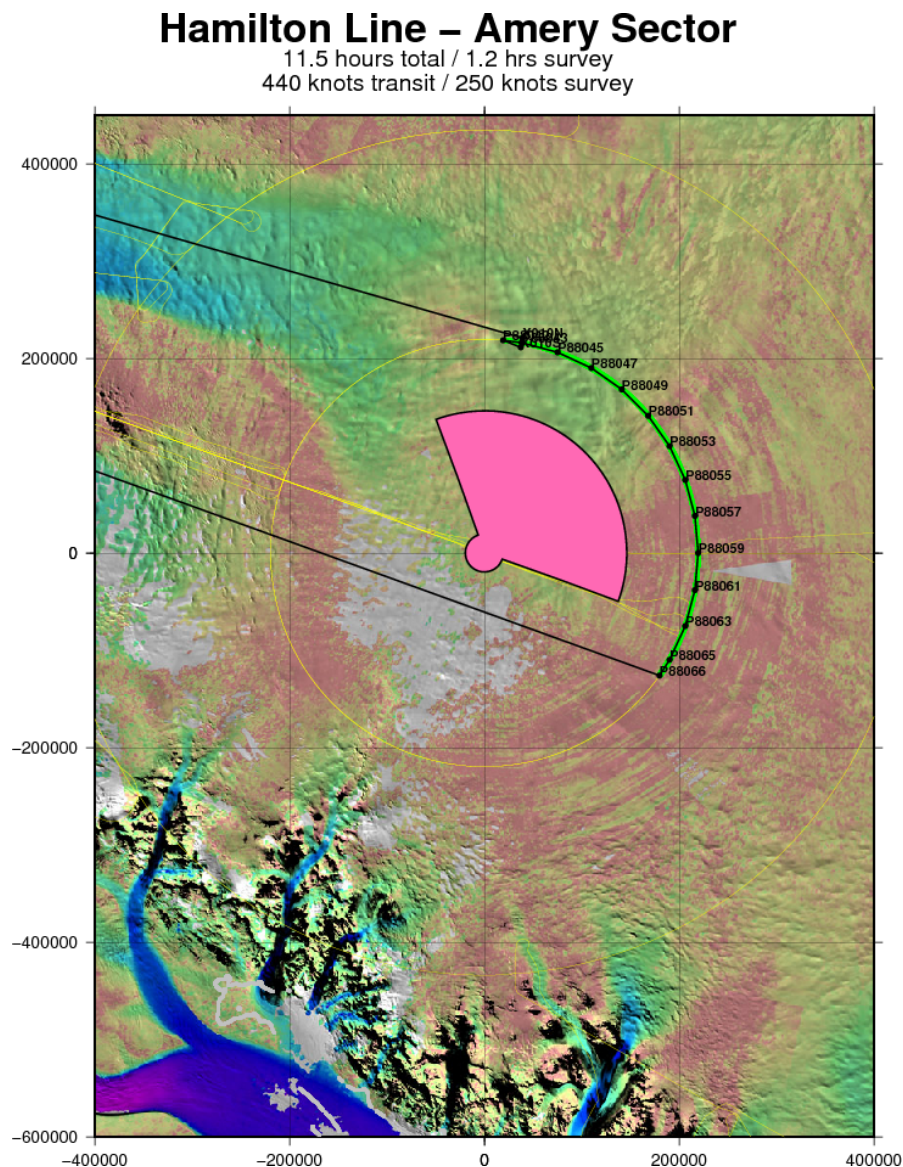
ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS5,IS6,IS15

Spacecraft Tracks: samples ~1/3 of all ICESat-2 tracks

Last Flown: 2016

Remaining Design Issues: none



Land Ice – Hamilton Line – TAM Sector

This flight's purpose is to sample the surface topography at the southern apex of many ICESat-II orbits. Specifically this flight samples the ground tracks on the Transantarctic Mountains sector of the Polar plateau. In this way, we can provide “ground truth” for every ICESat-II orbit with just three flights. The vertical stability of the surface must also be quantified for this approach to succeed, and this flight provides a repeat measurement for this purpose. This flight provides 40 km of overlap with each adjacent Hamilton Line mission. Finally, we fly a short crossover line in the overlapped section with the Hamilton Line – Amery Sector mission. This mission also covers the ICESat-2 traverse route. It is flown in a counterclockwise direction. Renamed in 2016 in honor of Dr. Gordon Hamilton.

Flight Priority: baseline (multi-year repeat flight)

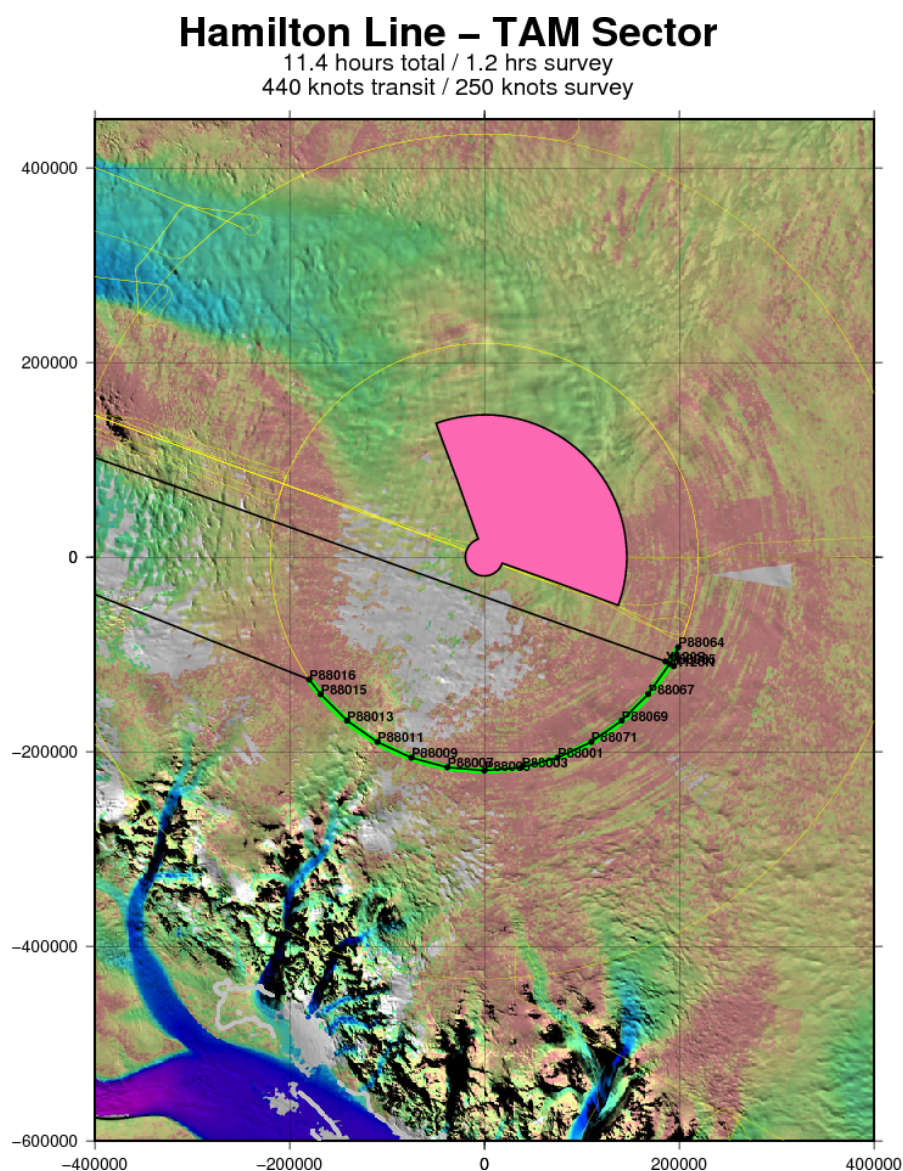
ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS5,IS6,IS15

Spacecraft Tracks: samples ~1/3 of all ICESat-2 tracks

Last Flown: 2016

Remaining Design Issues: none



Land Ice – Hamilton Line – Ronne Sector

This flight's purpose is to sample the surface topography at the southern apex of many ICESat-II orbits. Specifically this flight samples the ground tracks on the Ronne Ice Shelf sector of the Polar plateau. In this way, we can provide “ground truth” for every ICESat-II orbit with just three flights. The vertical stability of the surface must also be quantified for this approach to succeed, and this flight provides a repeat measurement for this purpose. This flight provides 40 km of overlap with each adjacent Hamilton Line mission. Finally, we fly a short crossover line in the overlapped section with the Hamilton Line – TAM Sector mission. It is flown in a clockwise direction. Renamed in 2016 in honor of Dr. Gordon Hamilton.

Flight Priority: baseline (multi-year repeat flight)

ICESat-2 latency: long

Science Requirements Addressed: IS1,IS2,IS3,IS4,IS5,IS6,IS15

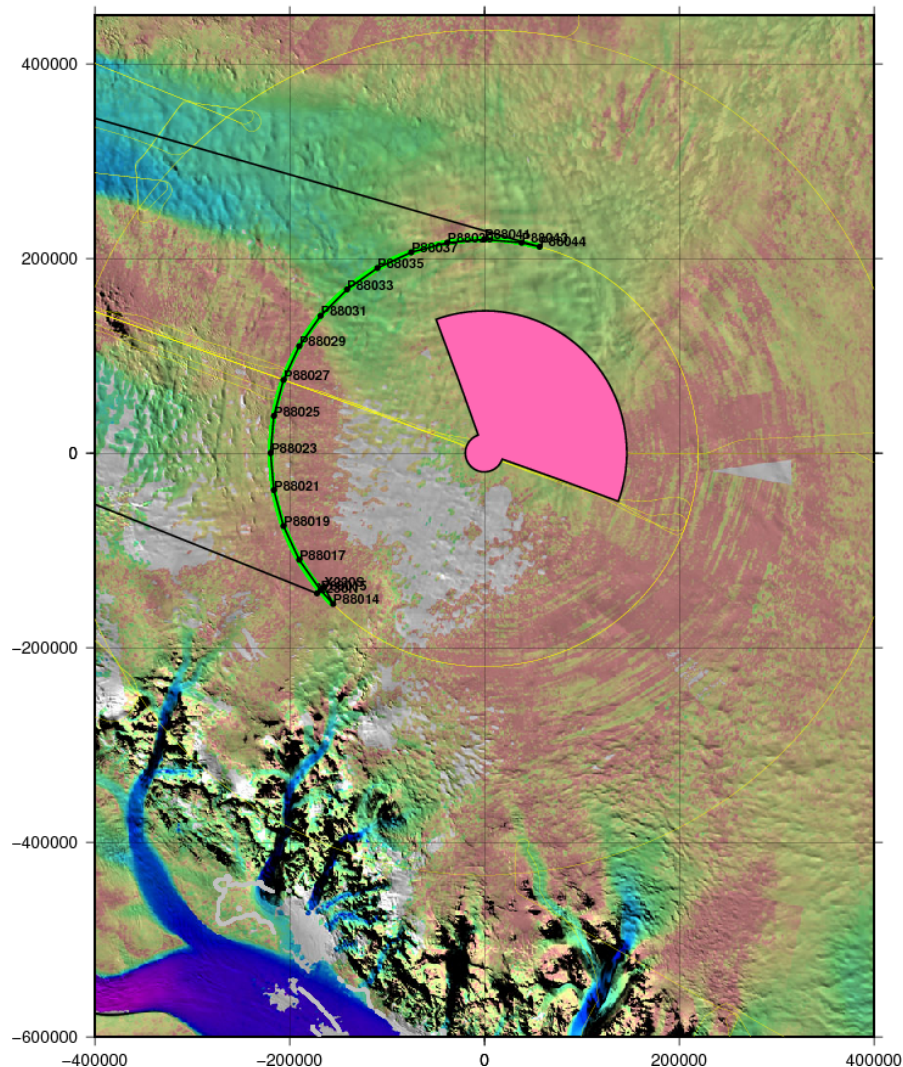
Spacecraft Tracks: samples ~1/3 of all ICESat-2 tracks

Last Flown: 2016

Remaining Design Issues: none

Hamilton Line – Ronne Sector

11.4 hours total / 1.4 hrs survey
440 knots transit / 250 knots survey



Appendix A: Avoidance of Wildlife and Other Protected Areas

Flight operations over Antarctica are restricted by several factors unique to Antarctica. Some of these factors stem from the fact that the United States is a signatory of the Antarctic Treaty, and certain portions of the Treaty require the signatories to protect wildlife and other designated areas of particular value. In practice, this means that OIB must avoid overflying known wildlife colonies, Antarctic Specially Protected/Managed Areas (ASPAs and ASMAs), and certain other sites, below specified AGL altitudes. In summer of 2014, the OIB Project Science Office completed a contractual arrangement with UK-based Environmental Research & Assessment (ERA) to obtain their database of Antarctic wildlife colony locations and specially protected areas. We have obtained an updated version of this database annually since then. We then incorporated an automated analysis which compared planned flights with the colony locations and with the ASPAs/ASMAs into the planning process for each flight. Based on that analysis, we adjusted several flight lines to avoid the indicated areas with explicit maneuvers and waypoints. The waypoints are labeled “AVOIDx” to cue navigators and flight crews to the urgency of avoiding the nearby areas. Even with these adjustments, however, it is impossible to predict the exact flight path of the aircraft in advance, and for this reason we specify a plan here to avoid all known areas with relevant flight restrictions.

The OIB science navigators will display point locations of all known wildlife colonies, and polygons defining the ASPA/ASMA boundaries, on an instance of the Soxmap navigation display and will monitor it carefully, calling out to the flight crew when an undesired upcoming overflight is foreseen. For the wildlife colonies, we use a lateral “stay-out” radius and a minimum overflight altitude somewhat more conservative than the ones used by ERA for their analysis. Thus, each colony location will be at the base of a three-dimensional cylinder which the aircraft will remain well-clear of. For the ASPA polygons, each one has its own overflight restrictions, and a comprehensive database listing these details may not be available in-flight. Thus we plan to steer clear of all ASPAs and ASMAs unless we know the permissible minimum altitude for a particular ASPA.

Our procedures for avoiding wildlife and ASPAs/ASMAs are as follows:

1. No overflights of wildlife colonies below 1000 m AGL within a radius of 2 km
2. No overflights of ASPAs/ASMAs at any altitude unless we know overflight is permitted for that particular area at a particular altitude.

We also expect that the DC-8 flight crew can display the wildlife locations and ASPAs/ASMAs on their flight instruments, providing an independent and redundant avoidance technique.

Appendix B: ICESat-2 Beam Patterns and OIB

The ICESat-2 ATLAS instrument emits 6 individual laser beams in a pattern fixed relative to the structure of the spacecraft. We refer to these 6 beams, when expressed in the frame of reference of the spacecraft itself (and NOT their positions on the earth's surface), as the “engineering beams”. The six beams are not identical – they are divided into “strong” and “weak” beams, three of each. Additionally two of the three “strong” beams are also known as TEP (Transmit Echo Path) beams, meaning that IceSat-2 records something similar to their start pulse waveforms. We also have a database known as the “reference ground track”, which are in fact the geodetic coordinates of the six beams along the surface of the earth. These are labeled with numbers 1, 2 and 3 designating, respectively, the left, center and right beam pairs, and by L and R within each pair designating the left or right beam. Thus the right beam of the center (nadir) beam pair is 2R, and the left beam of the right beam pair is 3L. For this discussion, the terms “left” and “right” are from the perspective of a person facing the direction of travel of the spacecraft.

Since the yaw attitude of the spacecraft is not fixed, the relationship between the six engineering beams and the six reference ground tracks are also not fixed, and we seek to understand how to map the engineering beams to the reference ground tracks in a simple and reliable manner. This is necessary because the 6 engineering beams are not identical to each other.

The six engineering beams are arranged in three pairs, with two near nadir, two at left, and two at right. The beams are labeled numerically 1-6. Each pair has one strong and one weak beam. The strong beams are the odd-numbered beams 1, 3 and 5, while the weak beams are the even-numbered beams 2, 4 and 6. The TEP beams are 1 and 3. The beam pairs are separated by ~3.3 km across-track, and the two beams in each pair are separated by ~90 m. But depending on the yaw attitude of the spacecraft, the relative locations on the ground of the strong and weak beams, and two TEP beams, varies.

For the reference ground tracks, the six beam paths (1L,1R,2L,2R,3L and 3R) are invariant with spacecraft attitude. Beam 2L, for instance, is always the left beam of the center beam pair, though beam 2L might correspond to different engineering beams depending on the spacecraft's yaw attitude. Figure B1 below depicts the reference ground track geometry for one ascending track near Summit Camp, Greenland.

For the purposes of ATM and OIB, we must identify reference ground tracks by single characters rather than the two-character 1L etc scheme, due to a number of different software limitations. So internally, we replace 1L with A, 1R with B, etc through 3R with F. For flight planning purposes, we also have three “virtual” reference ground tracks, X, Y and Z. Each corresponds to the centerline of a beam pair, with X for the left beam pair centerline, Y for the center pair, and Z for the right pair. This is in response to a recommendation from the OIB science team to fly the centerlines of the beam pairs in certain circumstances, rather than center the aircraft on specific individual beams. Figure B1 also shows the correspondence between the internal beam letters (A-F) in the reference ground track and the more generally-used two-character scheme.

For the fall 2018 Operation IceBridge deployment time frame, it is expected that the yaw orientation of ICESat-2 will be held to what is known as the “+X” orientation. In this orientation, the three weak beams lead the three strong beams along-track, the weak beams are the left beams of each pair, and the strong beams are the right beams of each pair. Furthermore, the TEP beams in this yaw orientation correspond to beams 2R and 3R in the reference ground track. See Figure B2 below (courtesy K.

Brunt) for a depiction of the engineering beam geometry for the +X spacecraft orientation.

Note that for time periods after the fall OIB deployment time frame, the yaw orientation of the spacecraft can be expected to change from time to time. Thus the mapping that follows is valid **ONLY FOR OCTOBER-NOVEMBER 2018** and **MUST BE REVISITED** for all subsequent time frames. The two colors in the table indicate that items highlighted in the same color remain in lockstep regardless of the spacecraft's yaw attitude, while items in different colors change in their relation to each other when yaw orientation changes. For instance, ref track ID 2L always corresponds to internal ref track letter C, and engineering beam 3 is always a strong beam with TEP. But the laser occupying ref track 3R is not always strong TEP beam #1.

| Ref track ID | Ref track letter (OIB internal) | Engineering beam # | Beam type | TEP |
|--------------|---------------------------------|--------------------|-----------|-----|
| 1L | A | 6 | weak | no |
| 1R | B | 5 | strong | no |
| 2L | C | 4 | weak | no |
| 2R | D | 3 | strong | yes |
| 3L | E | 2 | weak | no |
| 3R | F | 1 | strong | yes |

The table below identifies the geometric meaning of the “virtual” reference track letters X, Y and Z, which are the centerlines of the respective beam pairs. These are created (internal to ATM/OIB) for flight planning purposes because of a recommendation from the OIB science team that, in some cases, we place the aircraft not over a specific beam but over the center of a given beam pair. This is usually intended to maximize our chances of covering both beams of a pair with the ATM wide scanner (~250 m in width).

| Virtual track letter (OIB internal) | Corresponds to beam pair centerline |
|-------------------------------------|-------------------------------------|
| X | Left / 1 |
| Y | Center / 2 |
| Z | Right / 3 |

IceSat-2 at Greenland Summit

Red:A(1L), Green:B(1R), Blue:C(2L), Orange:D(2R), Magenta:E(3L), Cyan:F(3R)

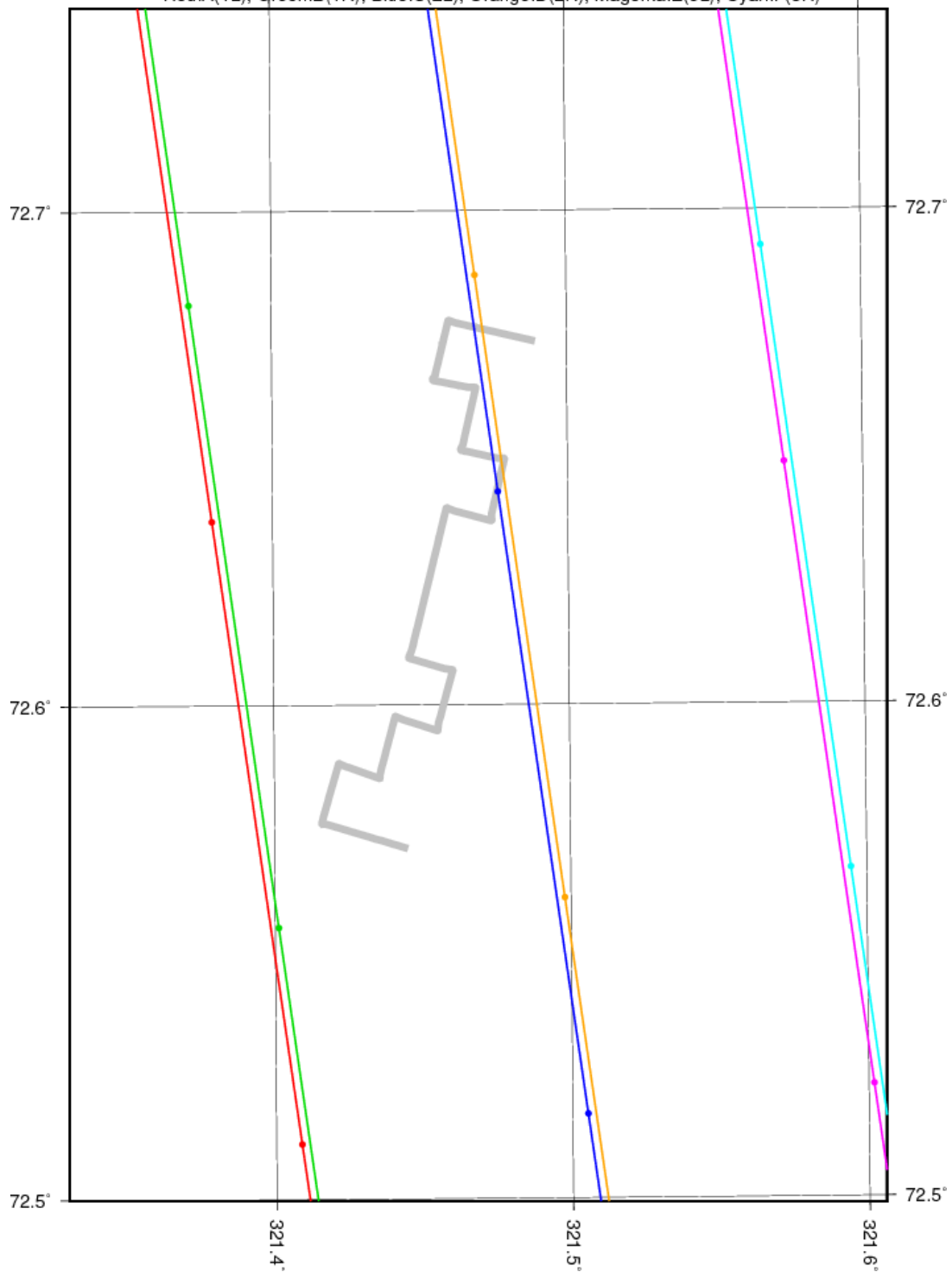


Figure B1. Ascending ICESat-2 reference ground tracks (ref orbit #0749) at Summit, Greenland.

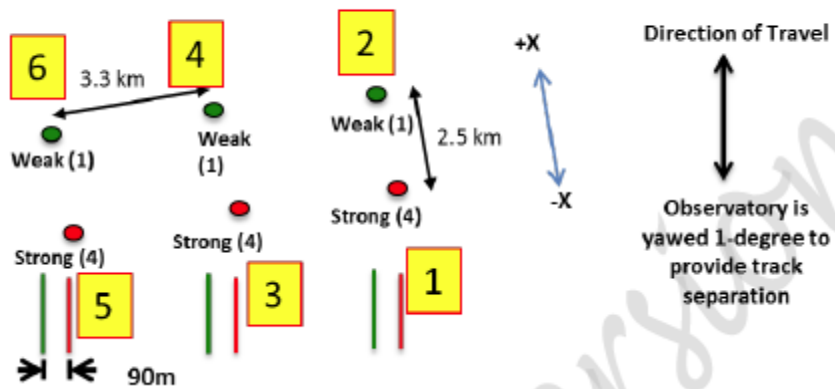


Figure B2. Spacecraft beam pattern for +X orientation (courtesy K. Brunt).

Appendix C: Sea ice drift corrections

For 2018, a requirement arose from the OIB science team to apply “drift corrections” to some of our planned flight paths. These corrections apply to two sea ice missions intended to be flown contemporaneously with ICESat-2: Sea Ice West Weddell and Sea Ice Mid-Weddell.

The purpose of the corrections is to modify our flight paths, according to the time differences between the expected time of our aircraft’s arrival at each of our waypoints and the overflight time of the ICESat-2 spacecraft, and according to the expected drift velocity of the sea ice. At each waypoint, the drift correction yields a position offset which can be applied in real-time as we fly. The result is that we improve the chance that our aircraft and the spacecraft measure the same swath of sea ice within a few hours, even as the ice itself drifts according to winds and currents.

An important component of the drift correction arises from the surface winds. Since the DC-8 has real-time winds readily available to the instrument team, we can use winds measured in-situ and in real time to inform the drift correction. Since we measure winds at altitude, while the surface winds are what is required, we will apply altitude-dependent scaling corrections to the wind speed as part of the drift correction algorithm.

Our plan for determining the drift corrections is as follows. When we initially enter the survey line, we will note the wind speed and direction at our altitude. If possible given visibility conditions and other factors, we will descend to as low as 500’ AGL and remain there for ~60 seconds to allow the air data measurements to stabilize, then note the wind speed and direction there, since we expect that winds at a lower altitude will better represent the surface winds than those measured at higher altitude.

Regardless of the altitude used to measure the winds, we will then enter these measurements into a software tool which will determine a velocity vector, representing our best estimate of the current sea ice drift rate and direction. For each waypoint in the flight plan, the software tool will calculate the time difference between our arrival at that waypoint and the spacecraft’s arrival over the Weddell, and use the drift correction velocity vector to calculate a position offset vector. These position corrections will then be applied to every remaining waypoint in the flight plan. We will repeat the wind measurement and drift correction procedure any time we note significant changes in the measured wind speed and/or direction.

The technical details of the drift correction algorithm are beyond the scope of this document, but are available upon request.